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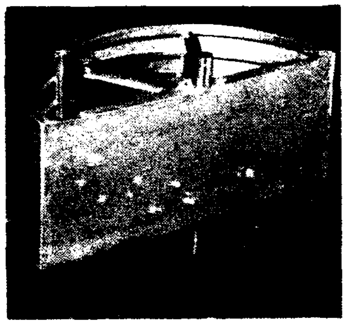

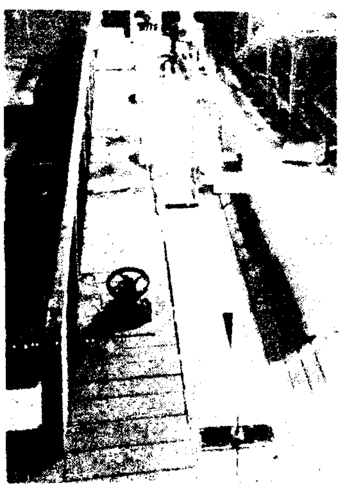

MELVIN PRICE LOCKS AND DAM AUXILIARY LOCK AND ROTARY LOCK CULVERT VALVE MISSISSIPPI RIVER, ALTON, ILLINOIS

Hydraulic Model Investigation

by

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13. ABSTRACT *(Maximum 200 words)*

Tests were conducted on a 1:30-scale model of the Melvin Price Auxiliary Lock, Alton, IL, and on a 1:12-scale model of the rotary valve proposed for use as the filling and emptying valves.

The lock model was built to study the effect of the rotary valves on the filling and emptying characteristics, the adequacy of the vertical slide gates to be used as a backup system, and the effects of flow through the adjacent spillway bays on the lock discharge outlets during emptying operations. The filling and emptying system consisted of intake manifolds upstream from the upper miter gate sill, longitudinal culverts, rotary valves, sidewall ports, and discharge outlets in the valve monolith. Unsatisfactory flow conditions were observed during spillway discharges in the vicinity of the lock discharge outlet caused by a discontinuity along the lock wall between the spillway pier and the discharge outlet. A wall was installed that streamlined the discontinuity and provided satisfactory flow conditions during spillway releases.

(Continued)

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Hydraulic systems	Mississippi River
Lock and Dam No. 26	Rotary valve

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A difference in water-surface elevations was observed between the lock discharge outlets with spillway discharges. This differential caused a transverse flow of water through the lock chamber and resulted in increased hawser forces and an adverse head on the downstream miter gate at the end of an emptying operation. A modified valve schedule was developed to eliminate the crossflow of water through the lock chamber and the adverse head on the downstream miter gate; however, this resulted in slightly longer emptying times.

Tests with the type 3 design filling and emptying system (with rotary valves) when compared to a similar conventional system using reverse tainter valves indicated significantly longer emptying times and slightly longer filling times.

The rotary valve model was built to study the hydraulic forces acting on the valve and pressure fluctuations on and around the valve and to observe conditions in the vicinity of the valve during steady-state and dynamic operating conditions.

The maximum pressure difference across the gate occurred when the valve reached between a 50 and 60 percent open position during an emptying operation. The maximum torque on the valve occurred when the valve reached a 50 percent open position.

PREFACE

The model investigation reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), on 21 March 1986 at the request of the US Army Engineer District, St. Louis (LMS).

The studies were conducted by personnel of the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), during the period September 1986 to July 1988. All studies were conducted under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL; R. A. Sager, Assistant Chief, HL; and J. L. Grace, Jr., and G. A. Pickering, past and present Chiefs, respectively, of the Hydraulic Structures Division (HSD), HL. The tests were conducted by Messrs. W. G. Davis, C. L. Dent, J. Cessna, R. A. Davidson, and R. G. Frazier, Locks and Conduits Branch, HSD, under the supervision of Mr. J. F. George, Chief, Locks and Conduits Branch. This report was prepared by Messrs. Davidson and Davis and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

During the course of the investigation, the following personnel visited WES to observe model operation, discuss test results, and correlate these results with concurrent design work: Messrs. B. L. McCartney and J. A. McPherson, HQUSACE; Messrs. M. Dove, T. Cox, and C. E. Thomas, US Army Engineer Division, Lower Mississippi Valley; and Messrs. J. Jaeger, J. Rapp, R. Parks, T. J. Mudd, A. Melidor, E. D. Haskett, P. Kornberger, M. Alvey, F. Burnett, R. Z. Sovar, K. Koller, and J. R. Niemi of LMS.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
foot-pounds (force)	1.355818	metre-newtons or joules
inches	25.4	millimetres
miles (US statute)	1.609344	kilometres
tons (force)	8,896.44	newtons

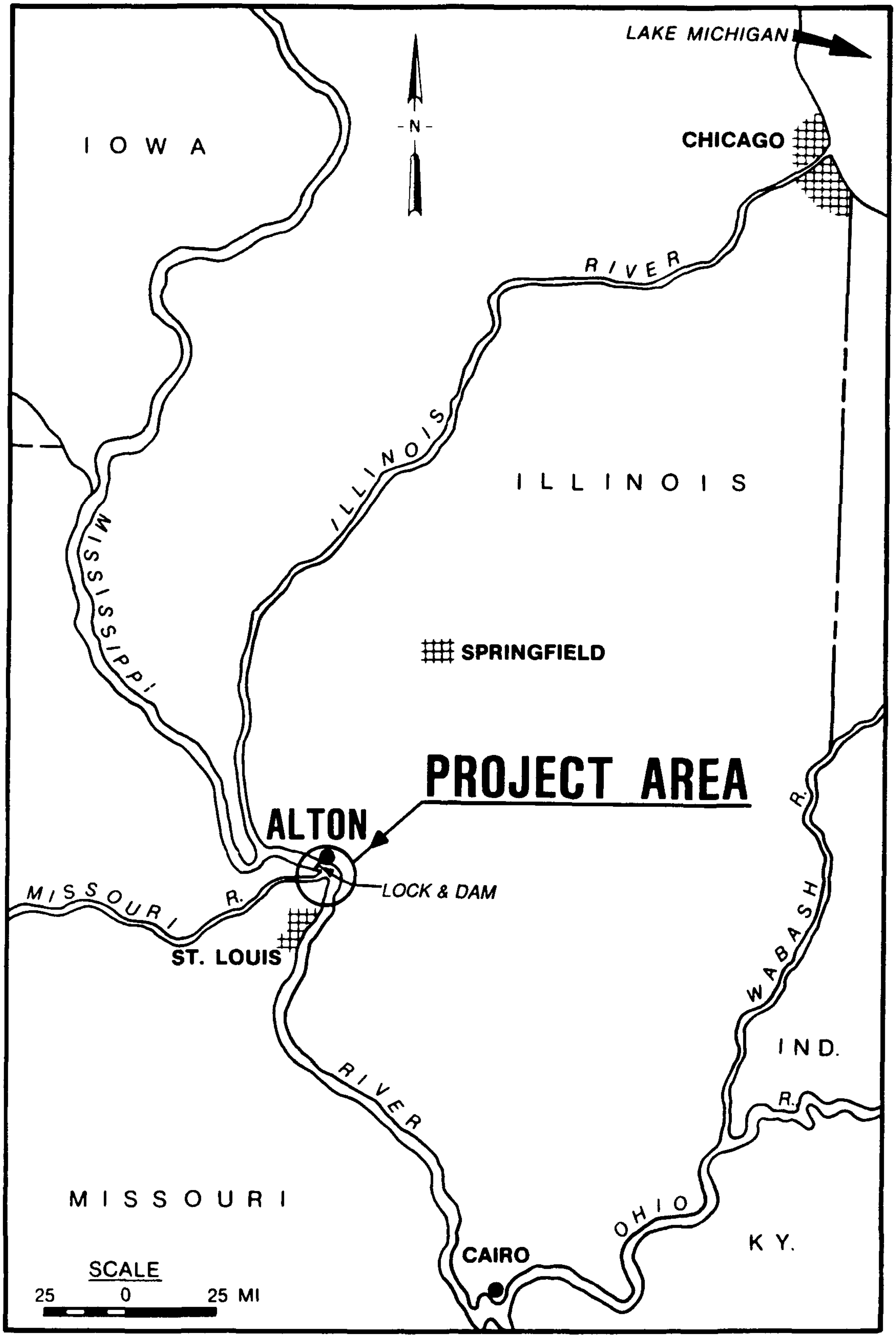

Figure 1. Project location map

MELVIN PRICE LOCKS AND DAM AUXILIARY LOCK AND ROTARY LOCK CULVERT VALVE, MISSISSIPPI RIVER, ALTON, ILLINOIS

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Melvin Price Locks and Dam structure will be constructed at Mississippi River mile 200.78 about 2 miles* downstream from the existing Lock and Dam No. 26 (Figure 1). The facility will include two locks and a gated spillway and stilling basin. The structure will consist of nine spillway gates, each 110 ft wide, with seven gates on the Missouri side of the main lock (110 ft wide by 1,200 ft long), two gates on the Illinois side of the main lock, and an auxiliary lock (110 ft wide by 600 ft long), which will be adjacent to the Illinois bank.

2. The auxiliary lock was selected to try to use a new concept for filling and emptying. The new concept is referred to as a rotary valve system. The rotary valves would be used for both filling and emptying the lock chamber (Figure 2) and would eliminate two of the four valves required in a conventional lock. However, this would require the discharge manifolds to be located in the valve monolith. The remaining hydraulic components of the side port filling and emptying system are typical for locks with this range of lifts (24-ft maximum and 16-ft normal lift). These components, shown in Plates 1-3, consisted of 8-port intake manifolds (Plate 2) located on the chamber side of each wall immediately upstream of the upper miter gate sill, 12- by 12-ft longitudinal culverts, and sidewall ports (Plate 3). Each longitudinal wall culvert consisted of 14 ports, each 2.625 ft wide by 4 ft high, spaced 28 ft on centers, staggered in opposite lock walls, and centered about the lock chamber length. Triangular deflectors were located on the lock chamber floor in front of the first five upstream ports in each culvert to

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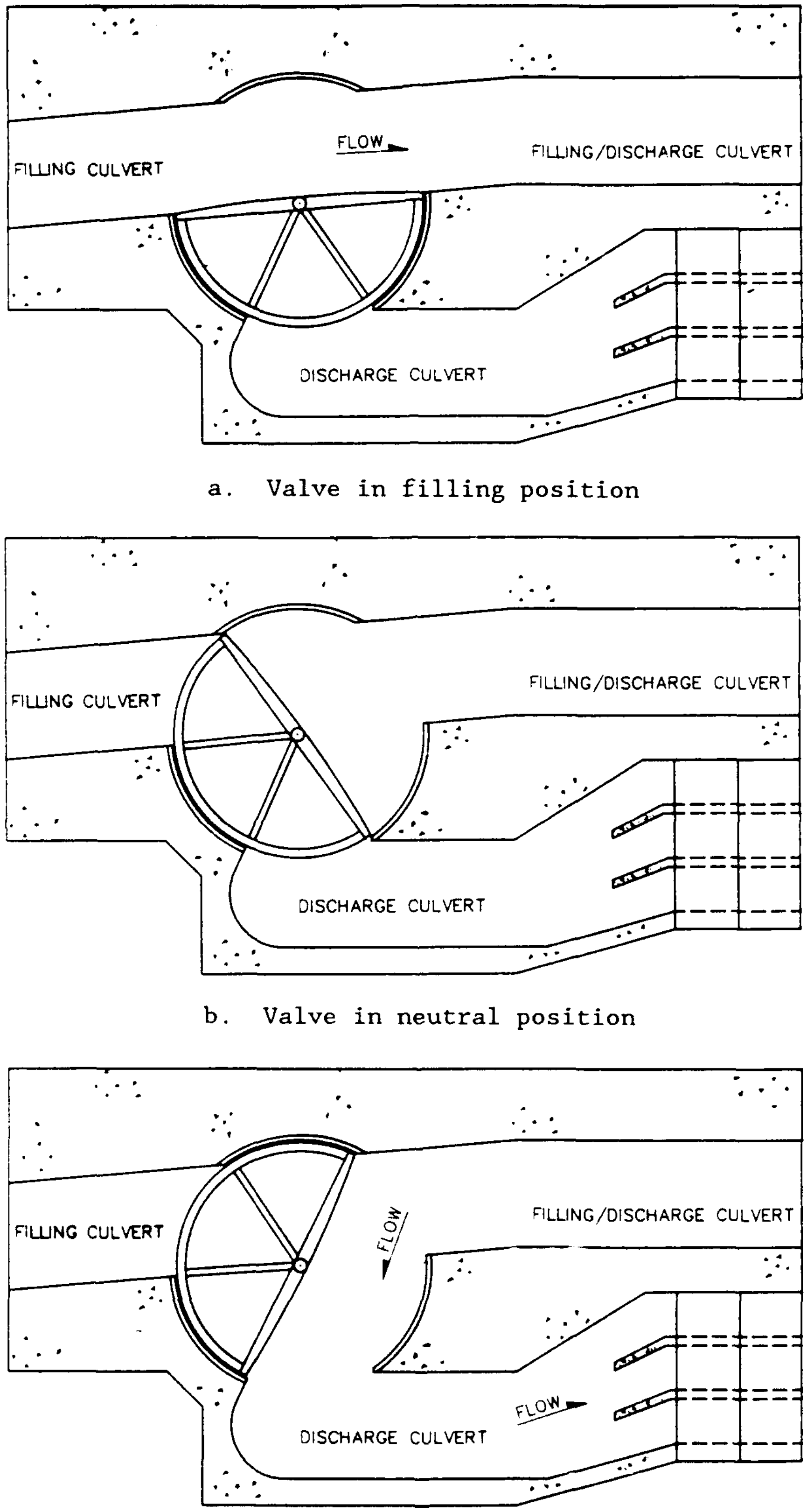
* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.



a. Valve in filling position

b. Valve in neutral position

c. Valve in discharge position

Figure 2. Rotary valve positions

reduce upstream longitudinal hawser forces during filling.

Purpose of Model Studies

3. Two models were deemed necessary to investigate the overall hydraulic performance of the rotary valve under various operating conditions. A model of the lock filling and emptying system was required to determine the effect of the rotary valves on the filling and emptying characteristics of the 600-ft lock, the adequacy of vertical slide gates to be used as a backup system in case the rotary valves were inoperable, and the effects of flow through the two spillway bays separating the locks on the lock discharge outlets during emptying operations.

4. The second model, a rotary valve model, was required to determine the hydraulic forces acting on the valve, pressure fluctuations on and around the valve, and conditions in the vicinity of the valve during steady-state and dynamic operating conditions.

5. Specifically, the model studies were to determine the following:

a. Hawser forces acting on barge tows during filling and emptying of the lock.

b. The time required to fill and empty the lock chamber.

c. Water-surface elevations and flow conditions at the lock discharge outlets with various spillway discharges.

d. If spillway discharges caused an adverse head on the lower miter gate when the lock chamber was empty.

e. Hydraulic forces acting on the valve.

f. Pressure fluctuations on the face of the valve.

PART II: THE MODELS

Description

The lock model

6. The 1:30-scale lock filling and emptying model (Plate 1, Figure 3) reproduced the 600-ft lock with the entire filling and emptying system, the two spillway bays adjacent to the lock, and a 250-ft-wide section of topography on the Illinois side of the lock from sta 4+00 upstream to sta 13+50 downstream. The lock walls, interior and exterior, were constructed of plywood and wood. The intake manifolds (Figure 4, Plate 2), culverts and sidewall ports (Figure 5), and valve monolith (Figure 6) were constructed of transparent plastic and sheet metal. The lock guide and guard walls both upstream and downstream were constructed of sheet metal. The spillway gates, crest, and piers were constructed of sheet metal. The topography was molded in sand and cement mortar to sheet metal templates. Nine sheet metal barges, each simulating a 195-ft-long by 35-ft-wide barge, were loaded with weights to produce the desired 9-ft draft.

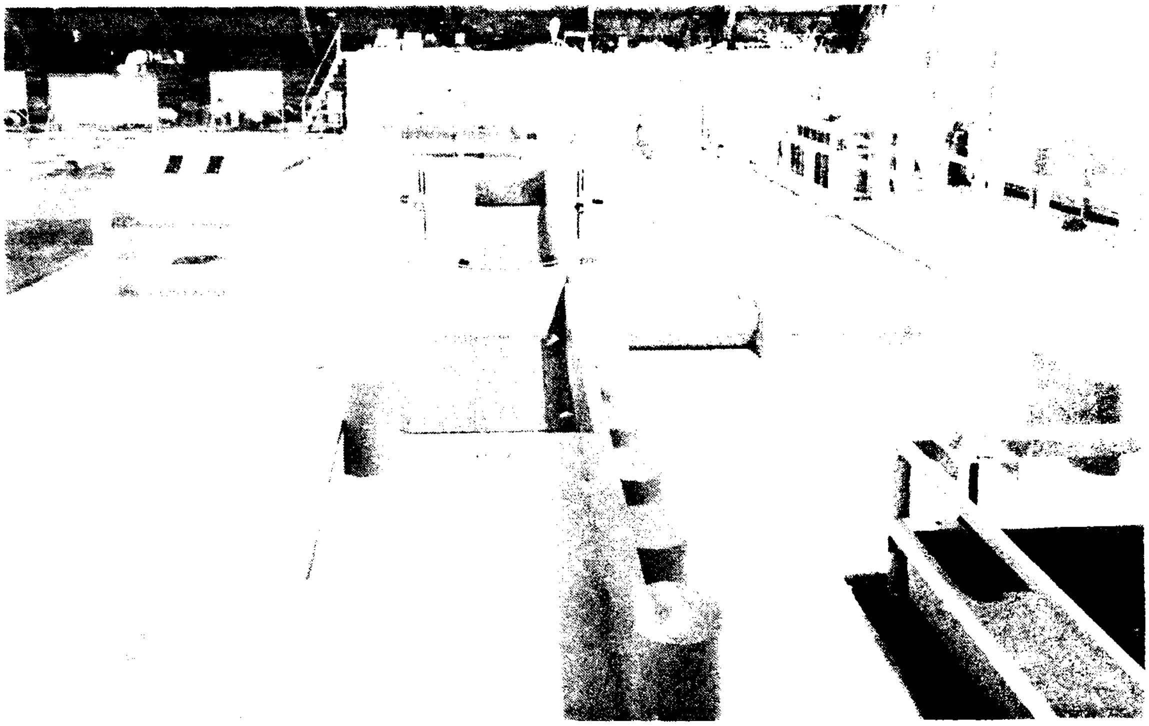
Rotary valve model

7. A study of loads exerted on the rotary valve was conducted at a scale of 1:12 in a model that reproduced the rotary valve (Figure 7), valve well, bulkhead slots, and approximately 100 ft of the culvert upstream and downstream of the valve (Figure 8). The upper pool and lower pool were controlled by vertical slide gates.

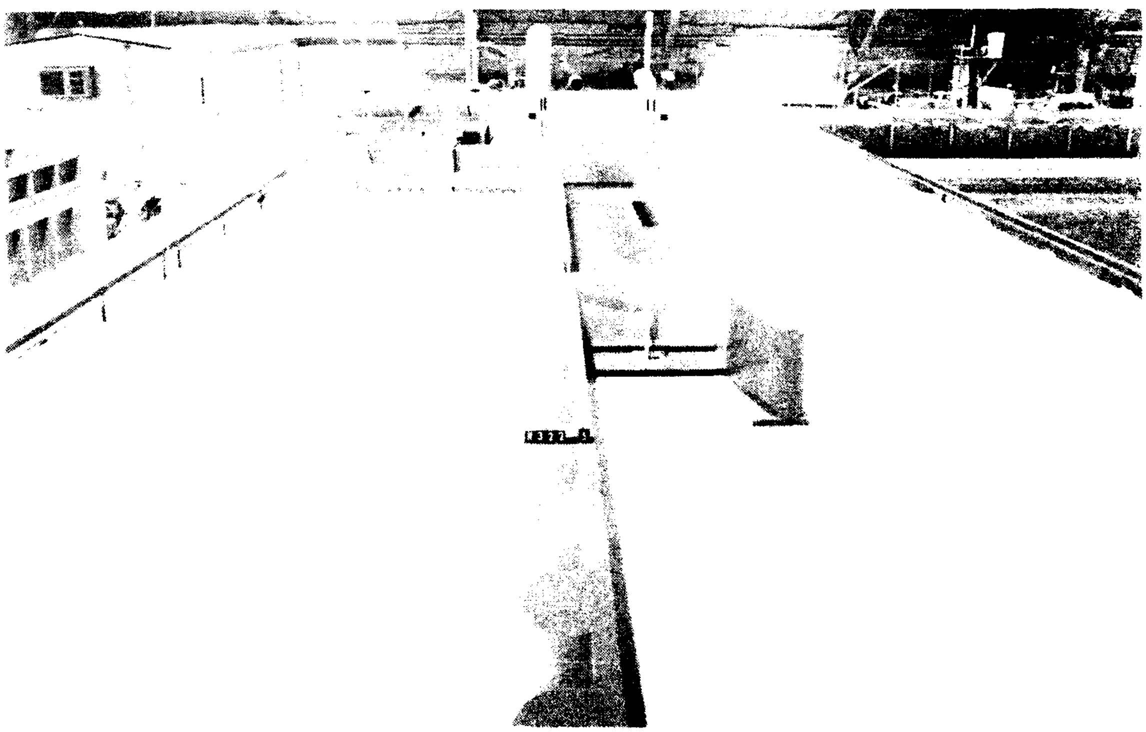
8. The valve well, bulkhead slots, and culverts were constructed of transparent plastic to permit observation of flow. All members of the rotary valve were constructed of brass. Seals were not installed on the valve because they would create excessive friction between the valve and the valve wall.

Model Appurtenances

9. Water used in the operation of the models was supplied by a circulating system. Both the headbay and tailbay of the lock model contained skimming weirs that maintained essentially constant upper and lower pools during filling and emptying operations. The skimming weirs in conjunction



a. Looking downstream



b. Looking upstream

Figure 3. The lock filling and emptying system model

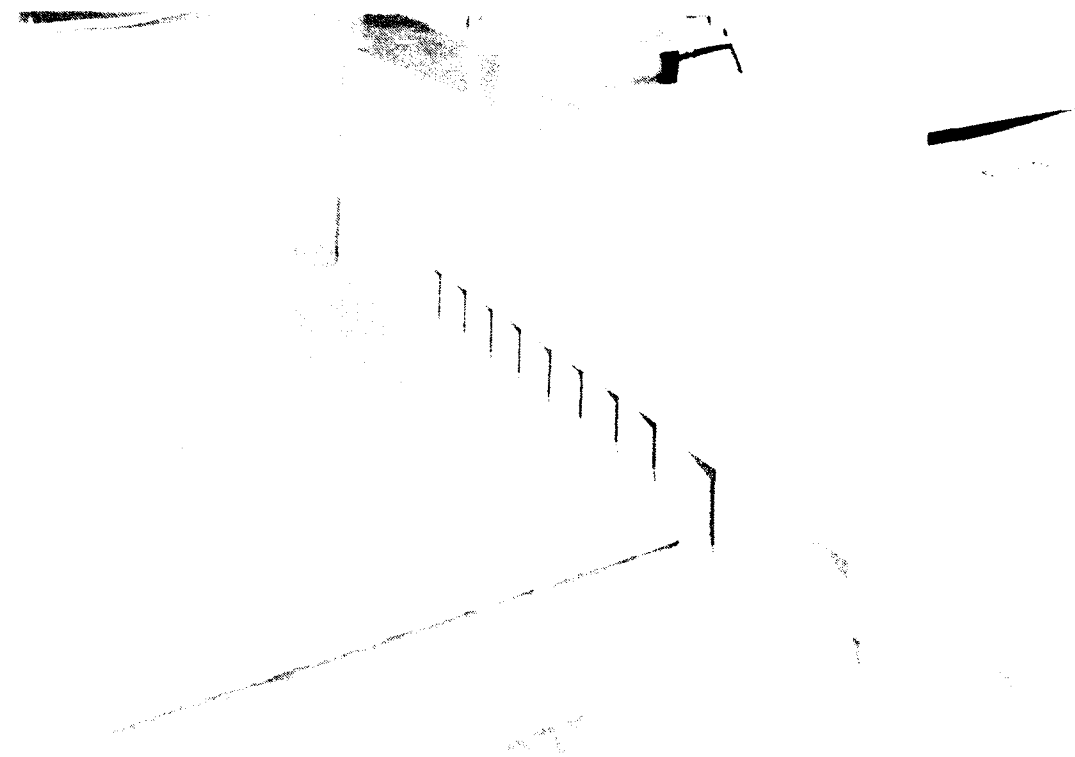


Figure 4. Intake manifold looking from the Illinois side

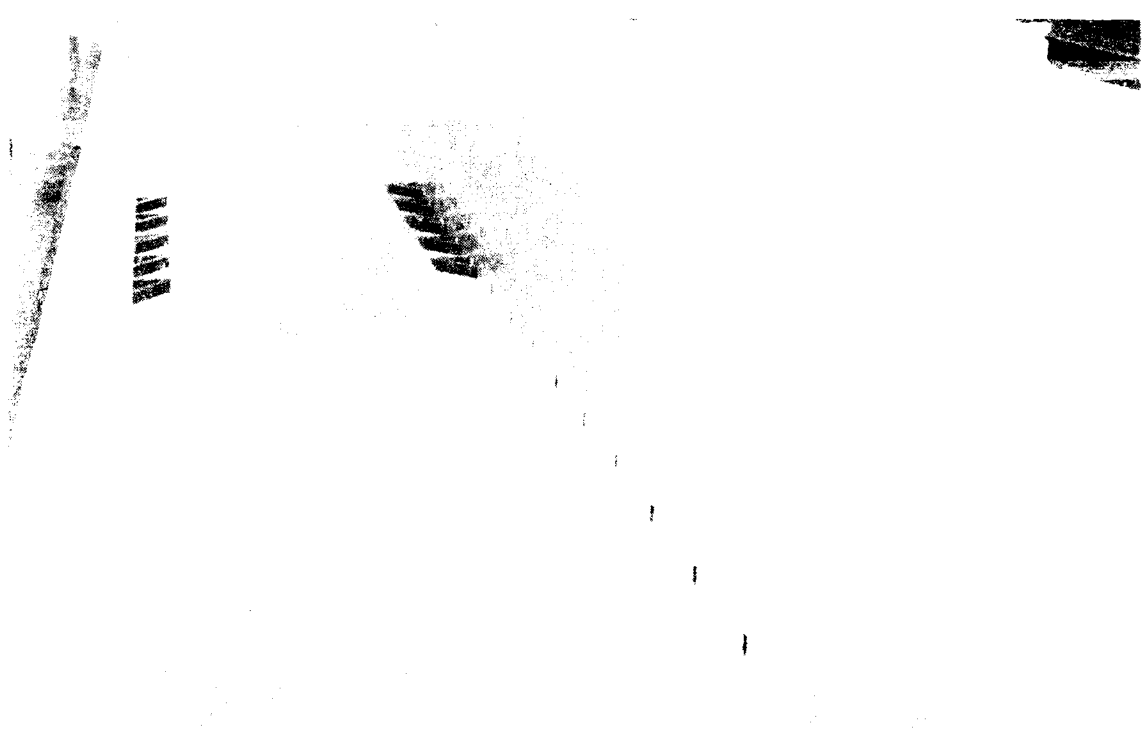


Figure 5. Lock chamber, culverts, and ports looking upstream

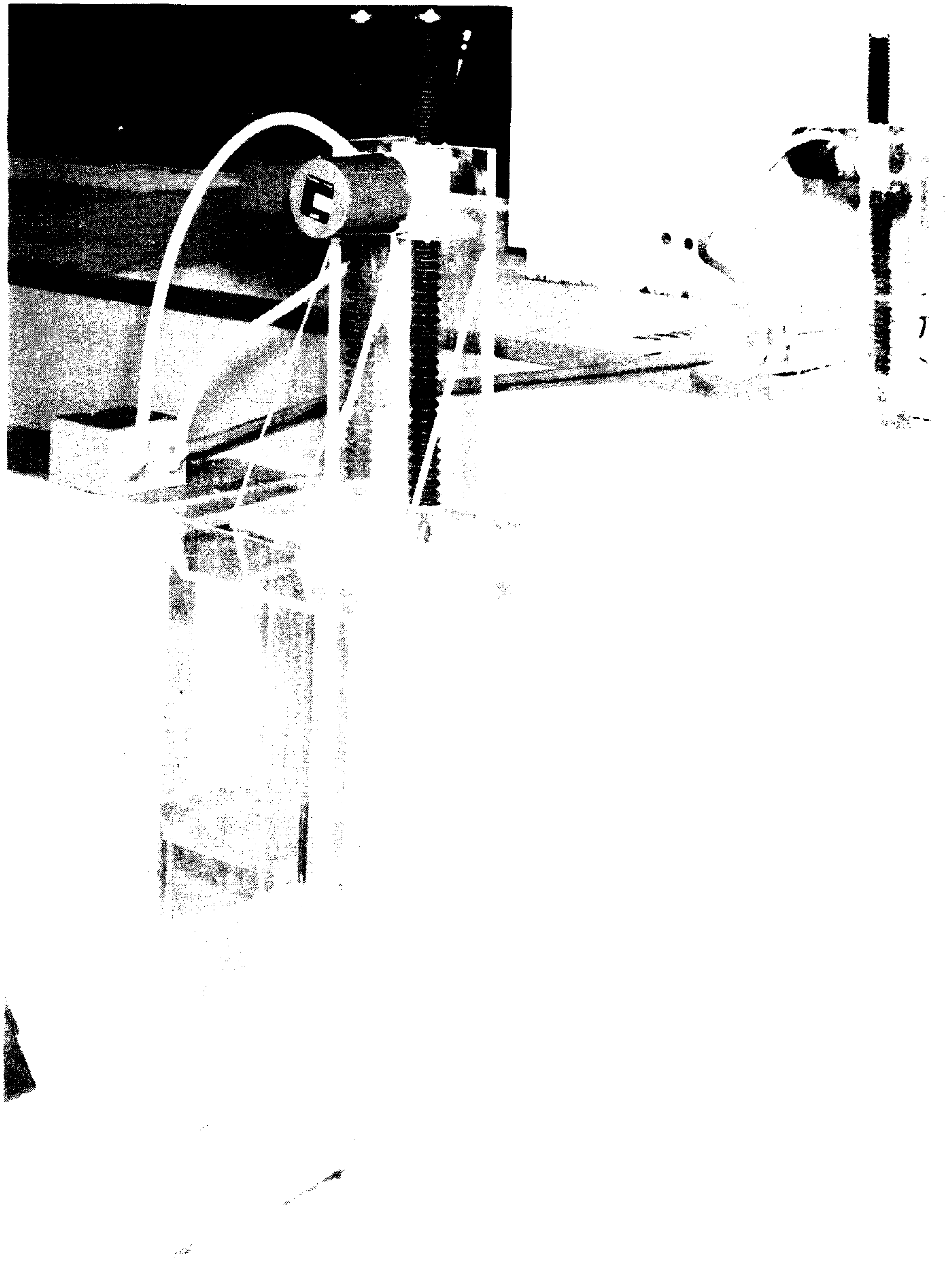
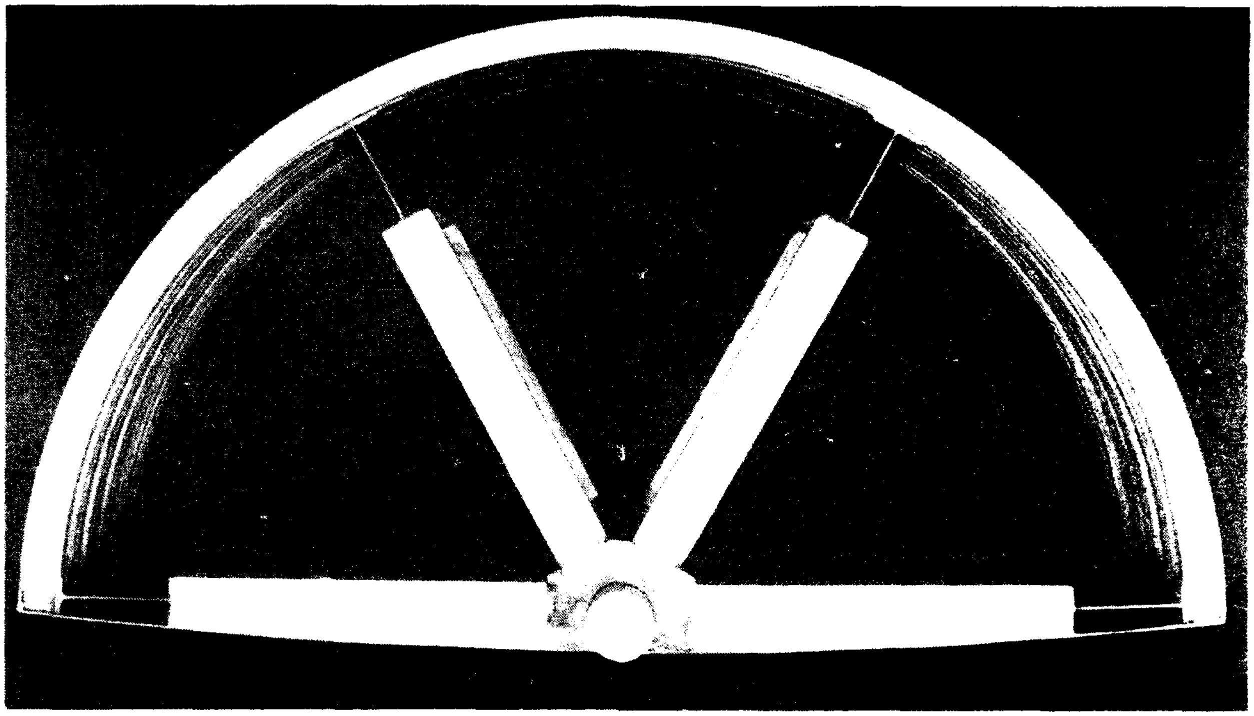
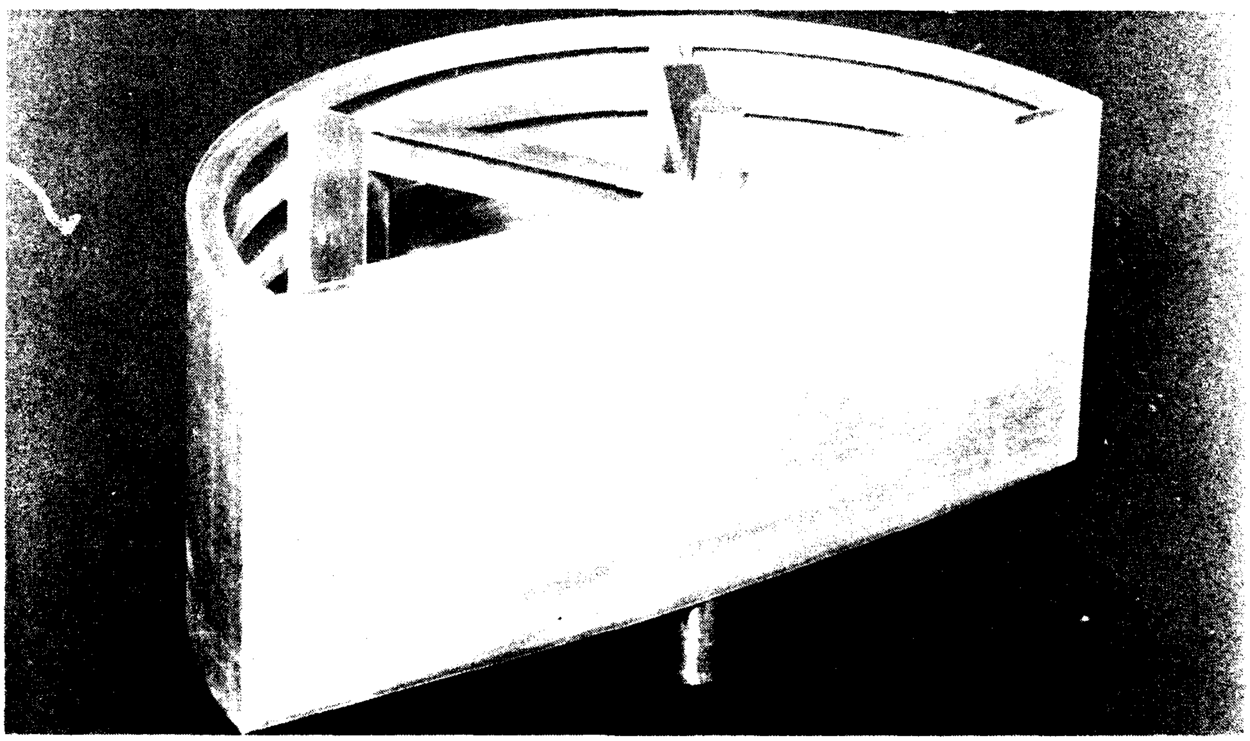


Figure 6. Valve monolith looking from the Missouri side

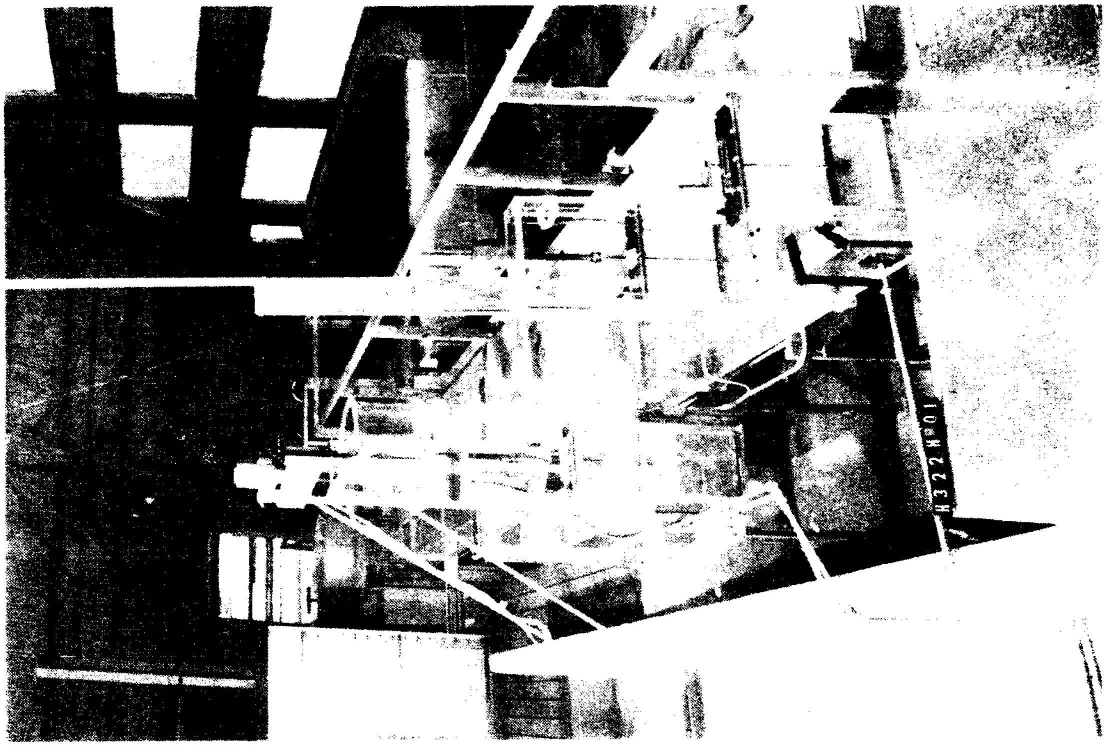


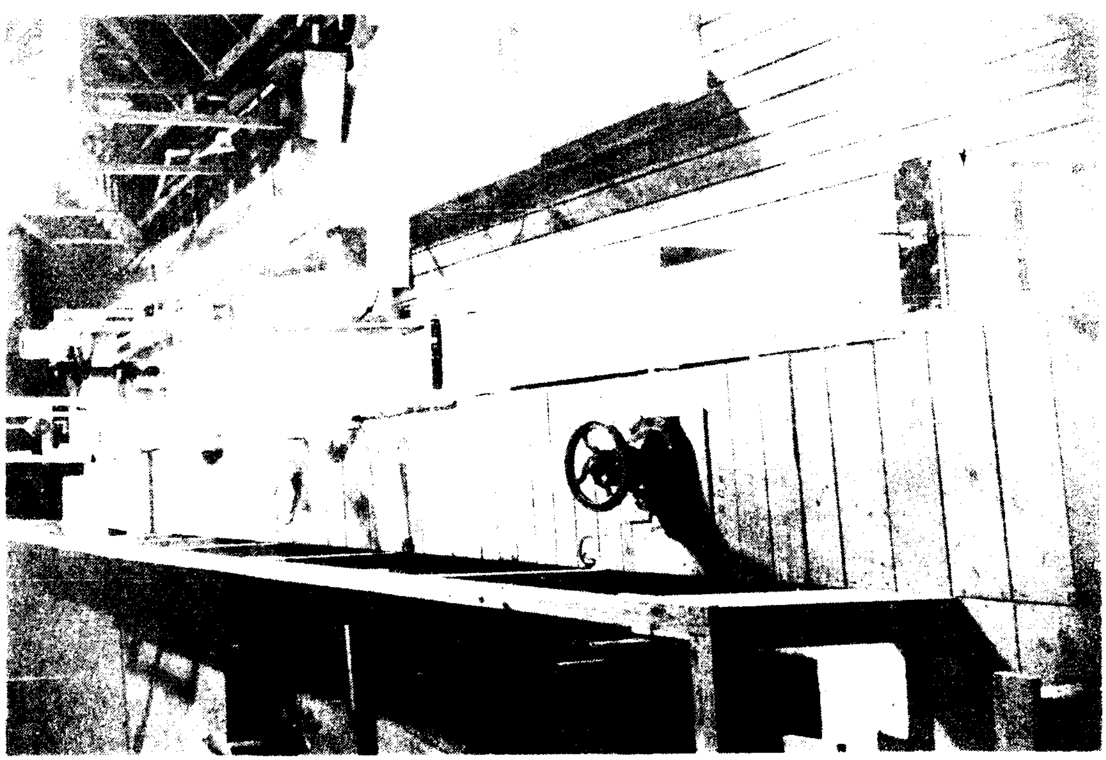
a. Top view



b. Front view

Figure 7. Rotary valve





with an adjustable tailgate could be raised or lowered to simulate any desired upper and lower pool elevations. Dye and confetti were used to observe subsurface and surface current directions.

10. A hawser-pull (force links) device (Figure 9) was used for measuring the longitudinal and transverse forces acting on a moored tow in the lock chamber during filling and emptying operations. Three such devices were used: one to measure the longitudinal forces and the other two to measure the transverse forces at each end of the tow.

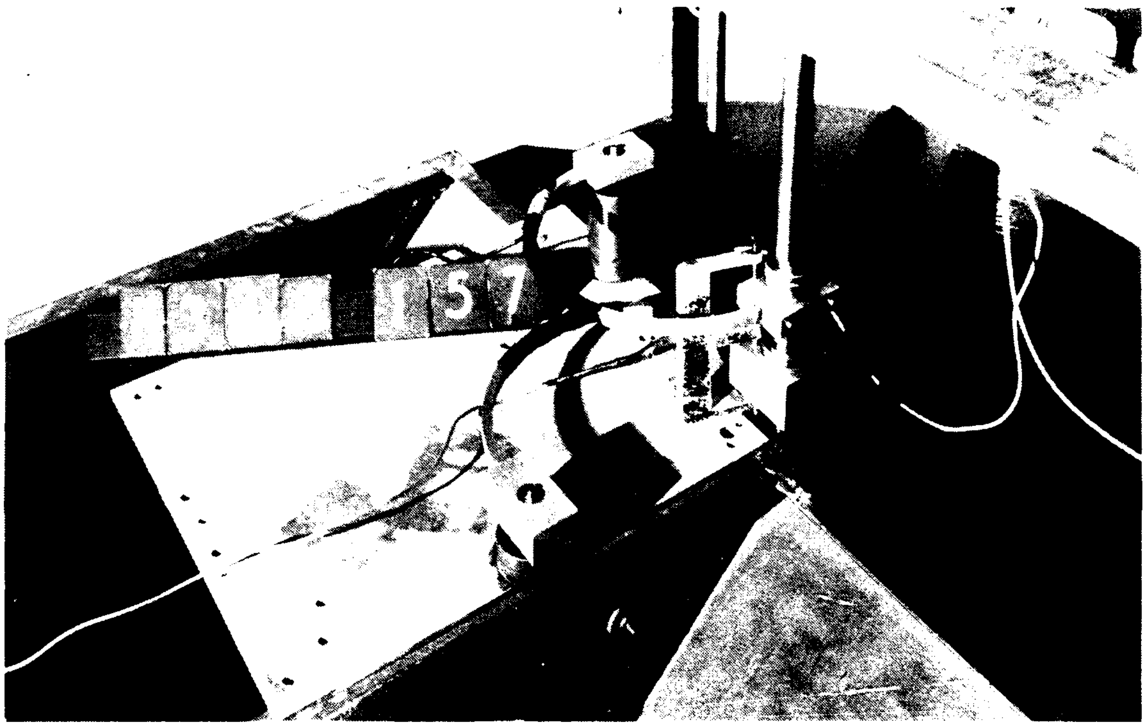


Figure 9. Hawser-pull measuring device on bow of tow

11. These links were machined from aluminum and had SR-4 strain gages cemented to the inner and outer edges. One end of the link was pin-connected to the tow while the other end was engaged to a fixed vertical rod and was free to move up and down with changes in the water-surface elevation in the lock. While the lock was filling and emptying, any horizontal motion of the tow caused the links to deform and vary the signal to a recorder. The links were calibrated by inducing deflection with known weights.

12. The movement of the culvert valves was controlled by servo-driven linear actuators that were regulated by the output of microcomputers.

Programming of the microcomputers resulted in varied output so that the desired valve schedules could be reproduced.

13. Capacitance-type probes were used to record the water-surface elevation in the lock chamber during filling and emptying operations. Other water-surface elevations were recorded with point gages.

14. Much of the data was recorded graphically on a commercial recorder. The sensing elements (mechanical to electrical conversion devices) located at various points on the models were connected by shielded cables to amplifiers where the outputs were stepped up to the level required for graphical recording.

15. The pressure in the culvert upstream and downstream of the valve in the rotary valve model was controlled by vertical slide gates that were driven by linear actuators (Figure 10). The vertical slide gates could be varied to accurately control the pressure in the culverts. The pressure upstream and downstream of the valve was measured with commercially available pressure cells. The pressure downstream of the valve was maintained at a constant pressure that corresponded to a given tailwater elevation.

16. A linear servo-actuator was used to control the motion of the

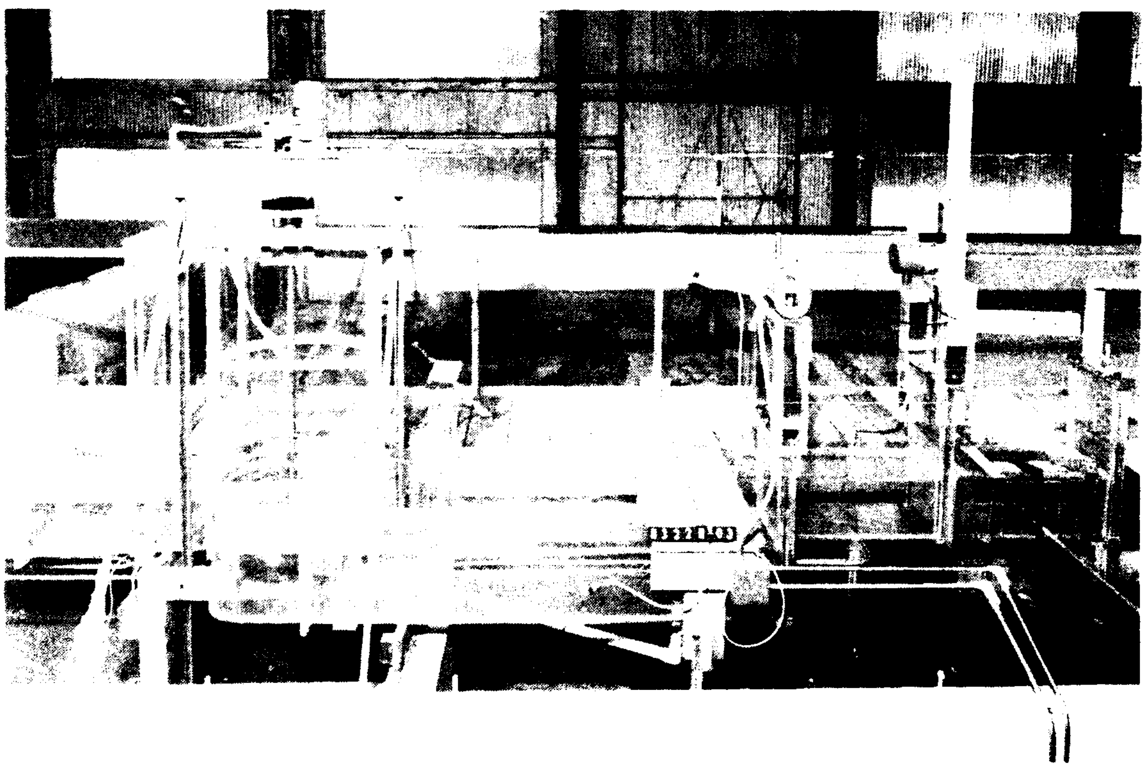


Figure 10. Orientation of slide gate and actuators

rotary valve. The linear servo-actuator was accurately controlled by a computer so that the valve could be operated at a scheduled rate.

17. Twelve pressure cells were installed at various locations on the face of the valve (Figure 11) to obtain a pressure distribution along the face of the gate.

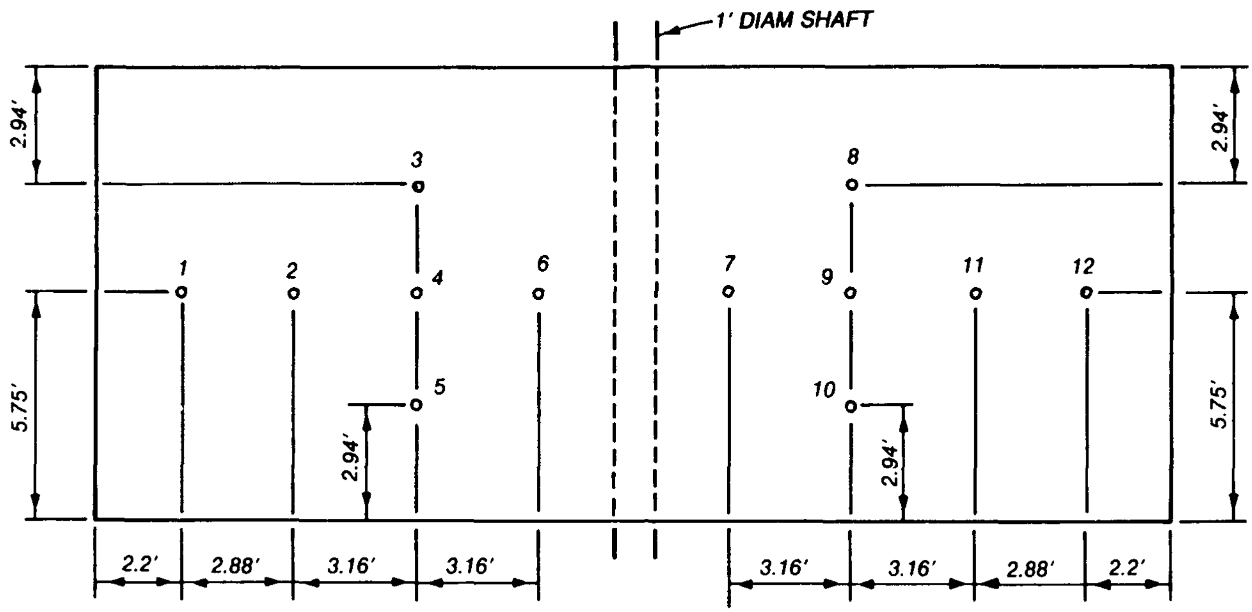


Figure 11. Pressure cell location on face of rotary valve

18. A commercial rotating shaft torque sensor was mounted in line with the shaft of the rotary valve to instantaneously and continuously measure the magnitude of the torque on the shaft.

Scale Relations

19. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for transference of model data to prototype equivalents are presented in the following tabulation. Measurements in the model of discharge, water-surface elevations, pressures, and forces can be transferred quantitatively to prototype equivalents by means of the scale relations.

Characteristic	Dimension*	Scale Relations Model:Prototype Lock Model	Valve Model
Length	$L_r = L$	1:30	1:12
Pressure	$P_r = L_r$	1:30	1:12
Area	$A_r = L_r^2$	1:900	1:144
Velocity	$V_r = L_r^{1/2}$	1:5.4772	1:3.4641
Discharge	$Q_r = L_r^{5/2}$	1:4,929.5030	1:498.8306
Time	$T_r = L_r^{1/2}$	1:5.4772	1:3.4641
Force	$F_r = L_r^3$	1:27,000	1:1,728
Weight	$W_r = L_r^3$	1:27,000	1:1,728
Frequency	$f_r = L_r^{-1/2}$	1:0.1826	1:0.2887
Torque	$t_r = L_r^4$	1:810,000	1:20,736

* Dimensions are in terms of length.

PART III: TESTS AND RESULTS

Lock Model

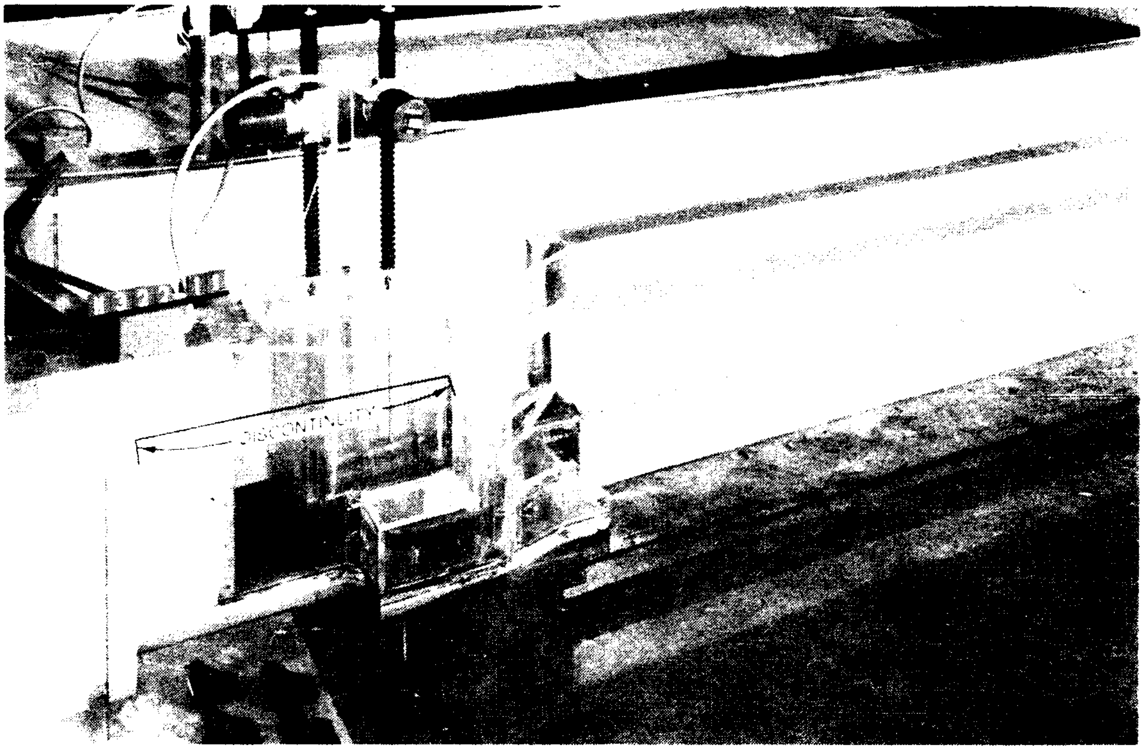
Initial tests

20. Spillway discharges. Initial observations revealed unsatisfactory flow conditions during spillway discharges in the vicinity of the lock discharge outlet on the Missouri side of the lock. A significant buildup of the water surface occurred on the upstream side of the lock valve monolith (Figure 12) because of a discontinuity present along the lock wall between the spillway pier and discharge outlet. A wall was installed in the model eliminating the discontinuity and resulting in satisfactory flow conditions in this vicinity (Figure 13).

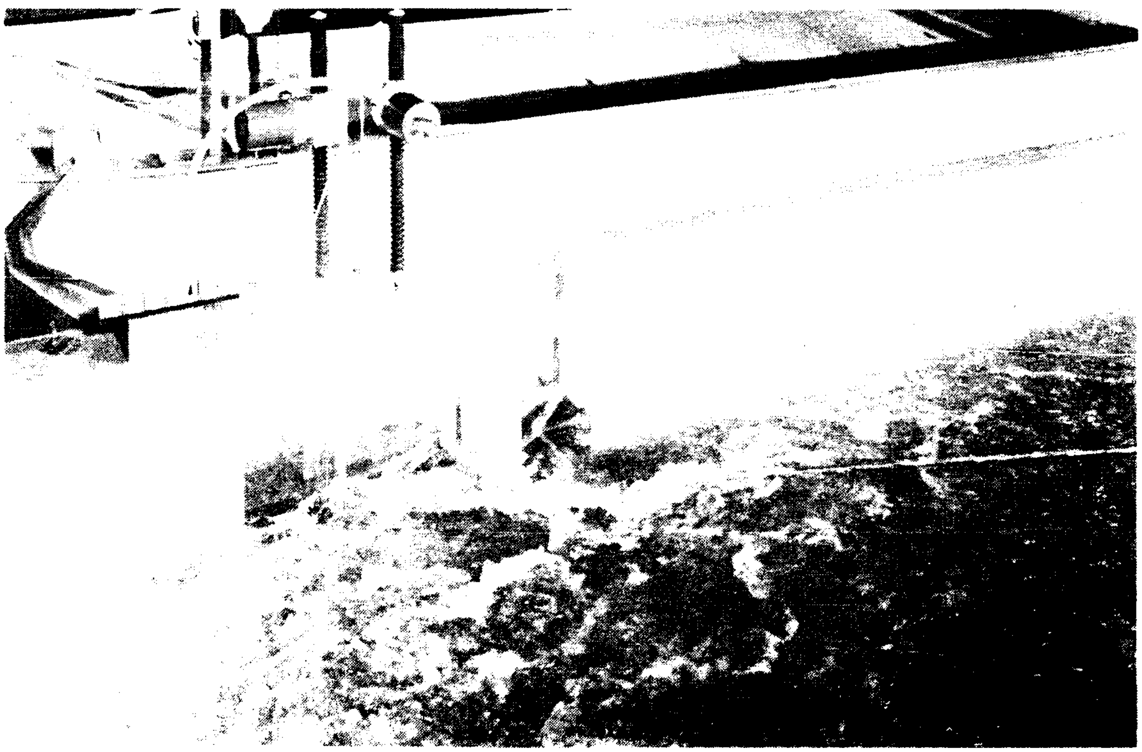
21. Hawser forces. Longitudinal and transverse hawser forces were measured on a nine-barge tow arrangement (Plate 4) with the type 1 (original) design filling and emptying system (Plate 3) installed. These initial tests were conducted with slide gates rather than the rotary valve in the valve monolith to evaluate the adequacy of vertical slide gates to be used as a backup system in case the rotary valves were inoperable. A detailed sketch of the culvert valve monolith showing the locations of the vertical slide gates used for flow control is presented in Plate 5. Initial tests were conducted with normal valve operations; 16- and 24-ft lifts; valve opening schedules of 2, 4, and 6 min; and no spillway flow. Maximum hawser forces recorded during filling and emptying operations are presented in Plates 6-9. Excessive longitudinal hawser forces were recorded during filling operations with a 24-ft lift. Hawser forces should not exceed 5 tons to meet US Army Corps of Engineers criteria. The large forces were in part due to the high port-to-culvert-area ratio of 1.02 and the lower submergence with the minimum lower pool (24-ft lift). Submergence is the difference in elevation between the lower pool and the lock chamber floor. A plot of filling and emptying times versus valve time for normal valve operations is shown in Plate 10.

Effects of spillway discharges

22. Water-surface differential. Due to the location of the lock discharge outlets relative to the spillway, a difference in water-surface elevation between the lock discharge outlets occurred with spillway discharges with gate openings of 5 ft and greater. This differential resulted in



a. Dry bed



b. Pool el 419, tailwater el 395, 15-ft gate opening on spillway bay 1

Figure 12. Unsatisfactory flow conditions in the vicinity of the lock discharge outlet looking from the Missouri side

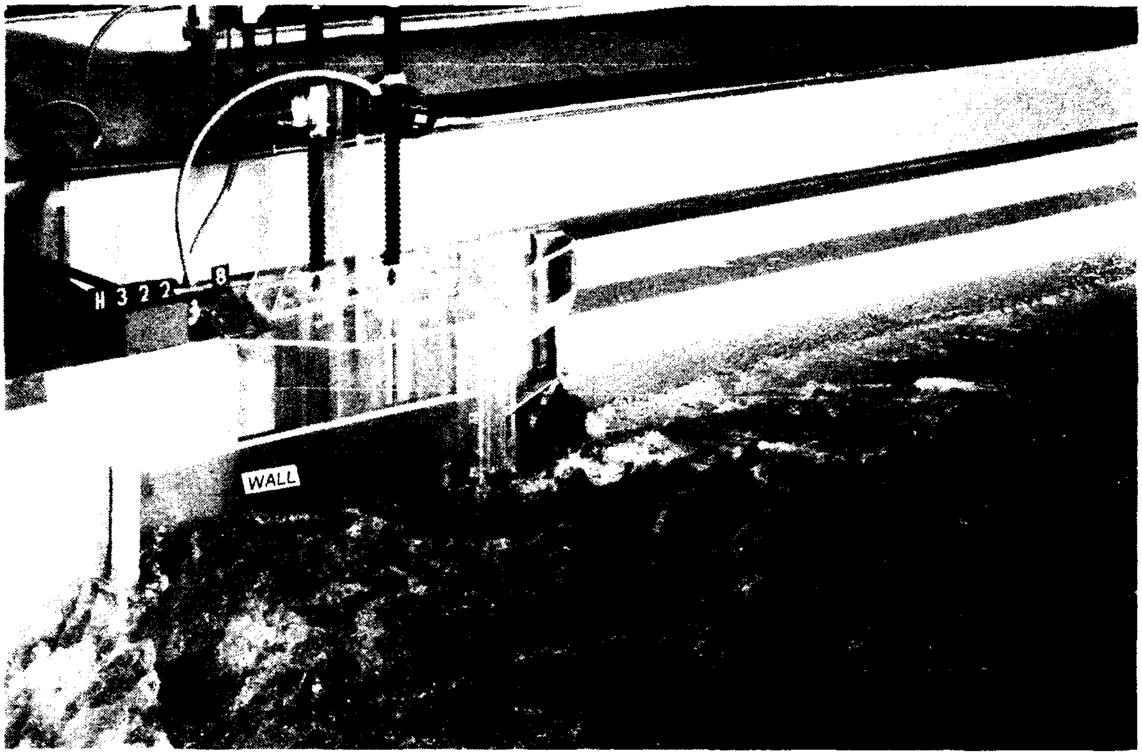


Figure 13. Wall installed in the vicinity of the lock discharge outlet to streamline flow, pool el 419, tailwater el 395, 15-ft gate opening on spillway bay 1 looking from the Missouri side

excessive undertravel of the lock chamber water surface during emptying operations. Undertravel for a conventional lock of this type would be approximately 0.6 ft. A plot of lock chamber pool elevation versus spillway gate opening (Plate 11) was developed for various operating conditions reflecting steady-state flow conditions after an emptying operation. These data are the result of leaving the emptying valves in the open position at the end of the emptying operation, which allowed water-surface elevations at various locations to reach equilibrium. The largest differential observed between the discharge outlets was 3 ft with the minimum lower pool (el 395*) and a 15-ft gate opening on spillway bay 1 (adjacent to the auxiliary lock). This differential caused a transverse flow of water through the lock and resulted in a lock chamber pool elevation of 393.9 (Plate 11), which caused a 1.1-ft adverse head on the downstream miter gate.

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

23. Hawser forces. Longitudinal and transverse hawser forces measured on a nine-barge tow arrangement with various spillway gate openings (Plates 12 and 13) revealed a significant increase in the transverse hawser forces for a 24-ft lift and a 15-ft gate opening on spillway bay 1. The increase in the forces acting on the barges was caused by flow through the lock chamber at the end of the emptying operation with the flow through the lock being driven by the 3-ft head differential between the discharge outlets. It should be noted that the test conditions for a 24-ft lift and a 15-ft gate opening on spillway bay 1 are a worst-case operational scenario and lockages would not occur under these extreme conditions.

24. In an effort to eliminate the excessive undertravel of the lock chamber pool and excessive hawser forces during emptying operations for a 24-ft lift during spillway discharges, modified valve schedules were developed. The modified schedules began closing the emptying valve on the Missouri side during emptying operations and ending its closure the instant the lock chamber pool reached the lower pool elevation. Hawser forces measured with the modified valve schedules are presented in Plate 14. The excessive undertravel of the lock chamber pool and excessive hawser forces were eliminated by using the modified valve schedules; however, this resulted in slightly longer emptying times.

25. The ports in the longitudinal culverts were modified to achieve a port-to-culvert-area ratio of 0.957 (Plate 15) as requested by the sponsor. Slide gates were again used as filling and emptying valves in the system. This was designated the type 2 design filling and emptying system.

26. Test results indicated that the hawser forces acting on the nine-barge tow arrangement were approximately the same for both the type 1 and type 2 design systems, as shown in Plates 6-9. Filling and emptying times were a little longer with the type 2 design system compared with the type 1 design system. That was expected due to the smaller port size in the type 2 design system. A comparison of these data are shown in Plate 10.

Rotary valves

27. Rotary valves were installed in the culvert valve monoliths (Plate 16, type 3 design filling and emptying system). Hawser forces measured with the type 3 design system were approximately the same as those recorded with the types 1 and 2 design systems. For comparison these data are presented in Plates 6-9. A plot of filling and emptying times versus valve time

for normal valve operations for types 1, 2, and 3 design filling and emptying systems is shown in Plate 10. These data indicate that the emptying times are less and the filling times are slightly more with the rotary valves (type 3 design) compared to those for slide gates (type 2 design) for the same port size in the filling and emptying culverts. However, when the type 3 design system is compared to a similar system using reverse tainter valves with the discharge outlets downstream of the lower miter gates, the conventional system is significantly more efficient, as shown in Plate 17. An uneven flow distribution was observed at the discharge outlets during testing. By modifying the discharge outlet, it is possible that the efficiency of the emptying system could be greatly improved. The port-to-culvert-area ratio of the conventional system used for comparison was 0.93. The data for the conventional system were obtained from Ables and Boyd.*

Rotary Valve Model

Steady-state tests

28. Initially, tests in the 1:12-scale valve model were conducted in a steady-state condition. A desired pressure was set and maintained upstream and downstream of the valve. These pressures corresponded to an expected pressure during a filling or emptying operation for a certain position of the valve.

29. Tailwater el 403. Pressures along the face of the gate and the torque in the shaft of the rotary valve for an emptying operation were obtained for tailwater el 403 using the procedure discussed in paragraph 28. This procedure was repeated for gate openings in 10 percent increments. The pressures along the face of the gate were plotted against the distance along the gate and are shown in Plates 18-22. The pressure difference between the left and right sides of the face of the valve increased until it reached a maximum between a 50 and 60 percent valve opening, then started decreasing. A maximum torque on the gate was observed at a 50 percent gate opening (Plate 23) and was found to be about 550,000 ft-lb.

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* J. H. Ables, Jr., and M. B. Boyd. 1966 (Nov). "Filling and Emptying Systems, Low-Lift Locks, Arkansas River Project; Hydraulic Model Investigation," Technical Report 2-743, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

30. Tailwater el 395. Pressures along the face of the valve and the torque in the shaft were obtained for tailwater el 395 and for gate openings in 10 percent increments. Pressure along the face of the gate versus distance along the gate is plotted in Plates 24-28. The pressure difference between the two sides of the gates increased until the gate reached a 60 percent gate opening, after which the pressure difference started decreasing. The maximum torque occurred at a valve opening of 50 percent (Plate 29) and was found to be about 950,000 ft-lb.

Dynamic tests

31. 2-min valve time. Pressures along the face of the gate and the torque in the shaft were measured using a 2-min valve speed. The pressure upstream of the valve was controlled as the rotary valve opened to simulate the emptying of the lock. The downstream pressure was controlled to simulate a tailwater elevation of 395. Pressure versus distance along the face of the gate for valve positions in 10 percent increments are provided in Plates 30-34. The maximum pressure difference between each side of the valve occurred when the valve reached 50 percent open. The maximum torque occurred when the valve reached a 50 percent open position (Plate 35) and was observed to be 780,000 ft-lb.

32. The pressure downstream of the valve was controlled to simulate a tailwater elevation of 403. The pressure upstream of the valve was controlled as the rotary valve opened to simulate the emptying of the lock. Pressure versus distance along the face of the gate for valve positions in 10 percent increments are provided in Plates 36-40. The maximum pressure difference between each side of the valve occurred between a 50 and 60 percent valve opening. The maximum torque occurred when the valve reached a 50 percent open position (Plate 41) and was observed to be about 510,000 ft-lb.

33. 4-min valve time. Pressures along the face of the gate and the torque in the shaft were measured using a 4-min valve speed. The pressure downstream of the gate was set to simulate a tailwater elevation of 395. Pressure versus distance along the face of the gate for valve positions in 10 percent increments are provided in Plates 42-46. The maximum pressure difference between each side of the valve occurred when the valve reached 50 percent open. The maximum torque occurred when the valve reached a 50 percent open position (Plate 47) and was observed to be 800,000 ft-lb.

34. The pressure downstream of the gate was set to simulate a tailwater

elevation of 403. Pressure versus distance along the face of the gate for valve positions in 10 percent increments is provided in Plates 48-52. The maximum pressure difference between each side of the valve occurred between a 50 and 60 percent open position. The maximum torque occurred when the valve reached a 50 percent open position (Plate 53) and was observed to be 440,000 ft-lb.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

35. The results of the model investigation indicated the desirability of modifying certain elements of the auxiliary lock as originally designed to improve flow conditions during spillway releases, reduce the excessive undertravel of the lock chamber pool, and reduce the excessive hawser forces during emptying operations with spillway discharges. This project was originally designed as a conventional reverse tainter valve system. The design had progressed significantly when the rotary valve system was proposed. Consequently, significant modifications from the conventional design were not possible due to impacts on design and project schedules.

36. Unsatisfactory flow conditions were present during spillway discharges in the vicinity of the lock discharge outlet caused by a discontinuity along the lock wall between the spillway pier and the discharge outlet. This discontinuity was eliminated by the addition of a wall, which streamlined the geometry upstream of the valve monoliths, resulting in satisfactory flow conditions during spillway releases.

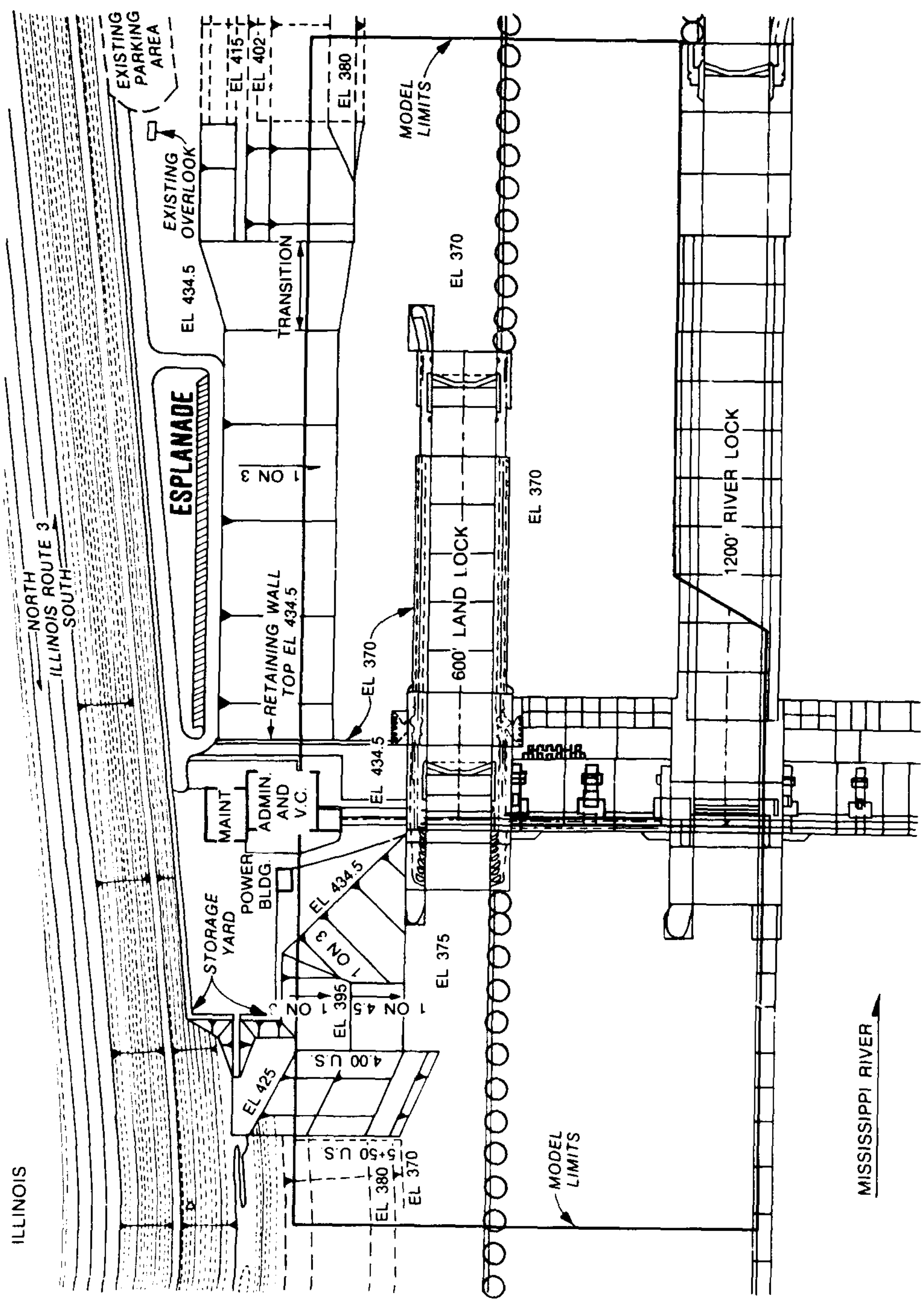
37. A difference in water-surface elevation between the lock discharge outlets occurred with spillway discharges as discussed in paragraph 22. This differential caused a transverse flow of water through the lock chamber from the Illinois to the Missouri side of the lock at the end of an emptying operation and created an adverse head on the downstream miter gate. The crossflow of water through the lock chamber significantly increased the transverse hawser forces acting on a moored tow during the later stages of an emptying operation. Tests indicated that a modified valve schedule could be developed to eliminate the crossflow of water through the lock chamber and the adverse head on the downstream miter gate; however, this resulted in slightly longer emptying times.

38. The three different filling and emptying systems tested yielded very similar results with respect to hawser forces measured on moored tows and filling and emptying times. However, when the type 3 design system was compared to a similar system using reverse tainter valves with the discharge outlets located downstream of the lower miter gates, the conventional system was significantly more efficient in emptying the lock chamber and slightly more efficient in filling the chamber. By modifying the discharge outlet of

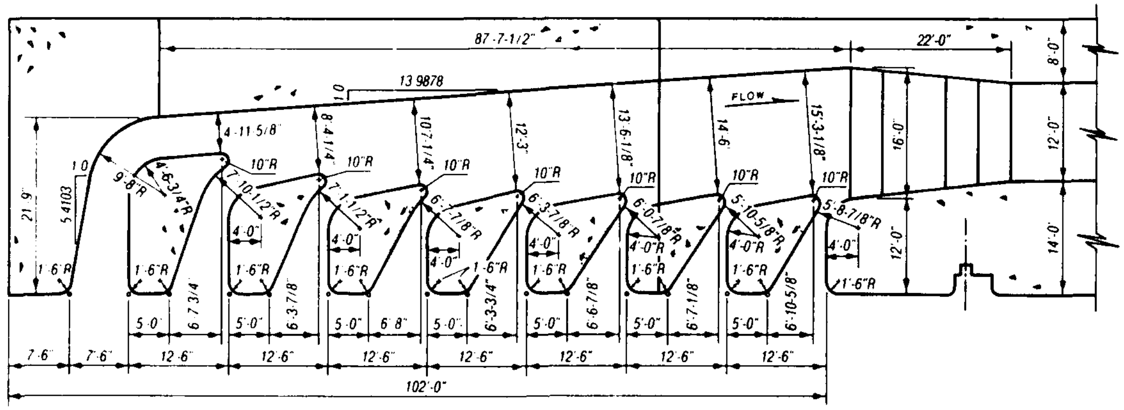
the rotary valve system it is possible that the efficiency of the emptying system could be greatly improved.

39. The maximum pressure difference across the gate occurred when the valve reached between a 50 and 60 percent open position during an emptying operation.

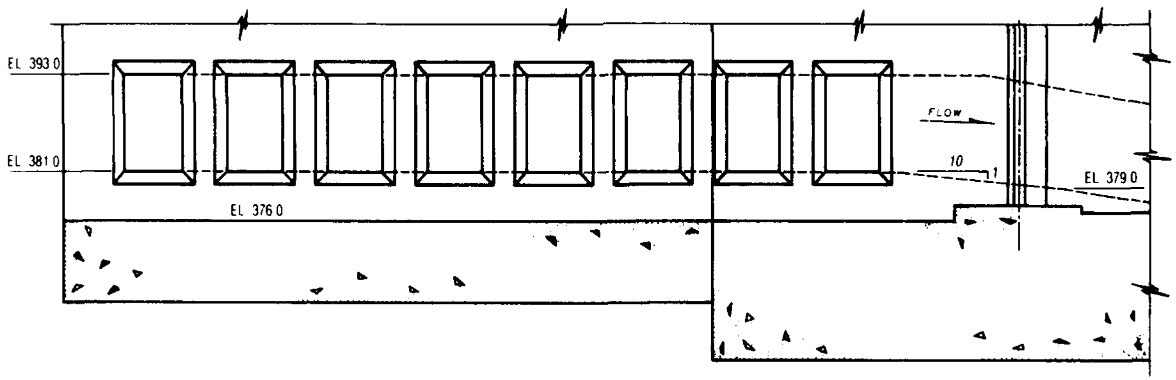
40. The maximum torque on the valve occurred when the valve reached a 50 percent open position and was approximately 800,000 ft-lb for an emptying operation with a tailwater elevation of 395.



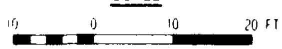
GENERAL PLAN



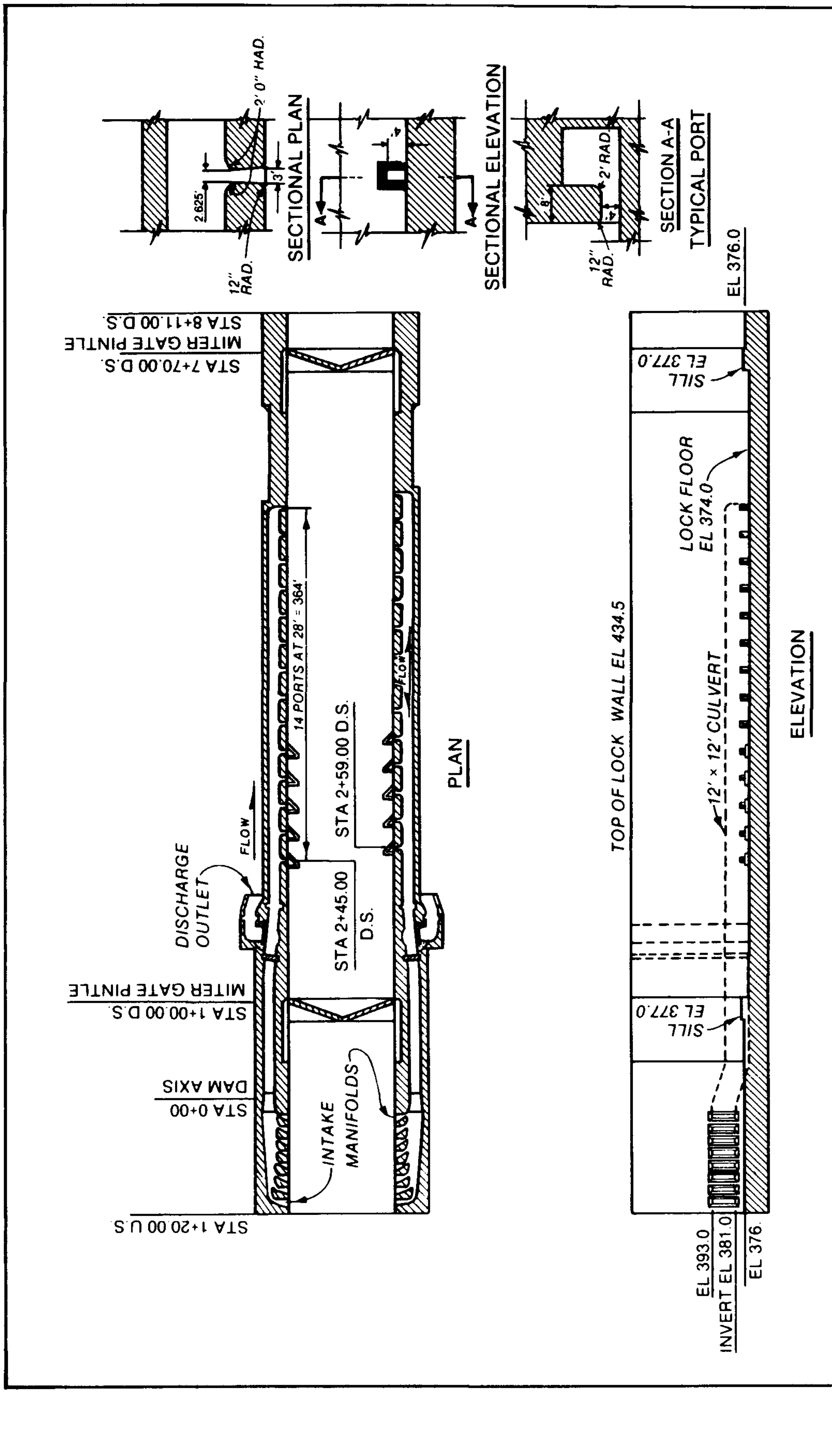
SECTIONAL PLAN OF CULVERT INTAKE



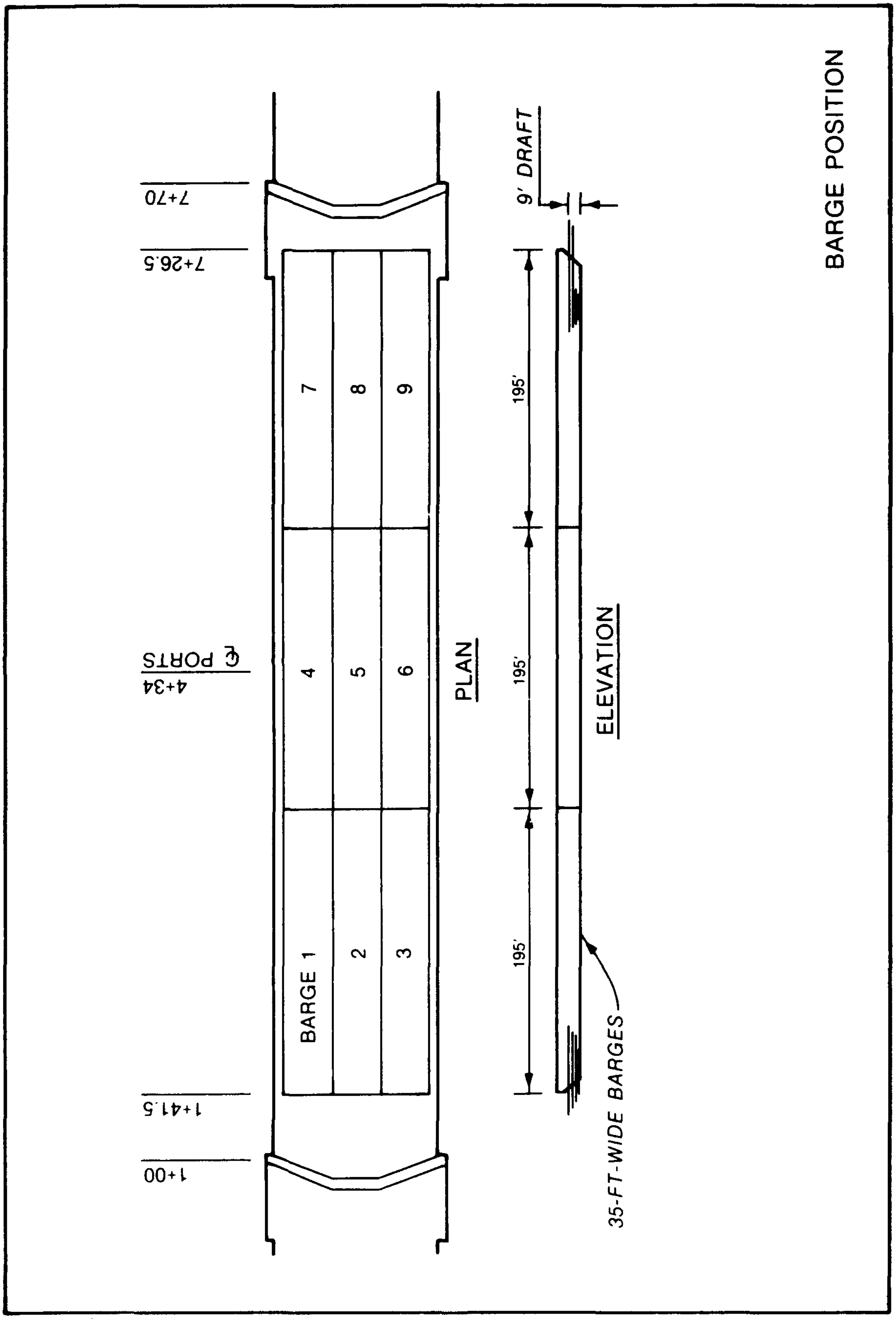
LOCKSIDE ELEVATION OF INTAKE PORTS

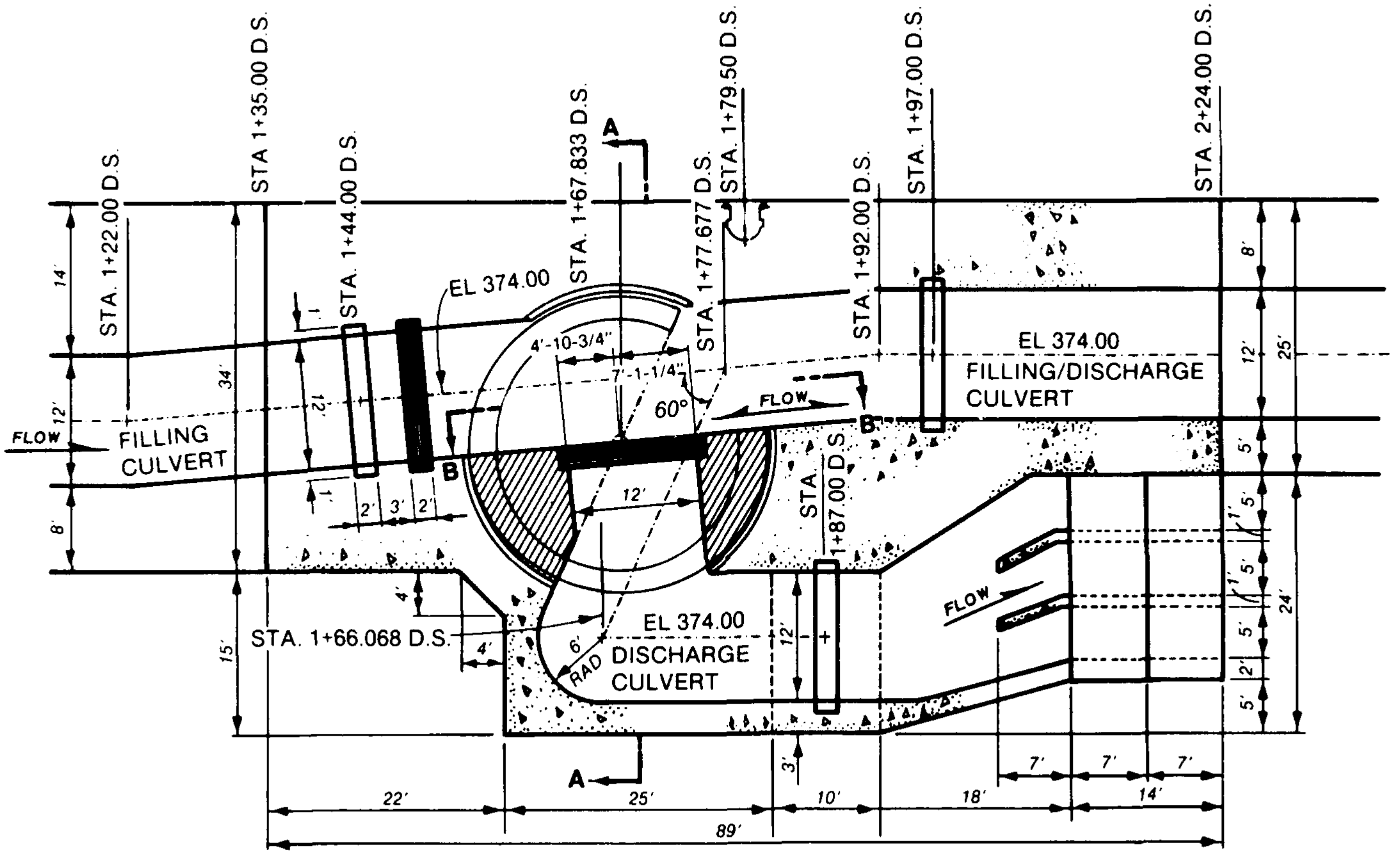


INTAKE MANIFOLD
TYPE 1 (ORIGINAL) DESIGN



TYPE I (ORIGINAL) DESIGN
FILLING & EMPTYING SYSTEM


BARGE POSITION
PLAN
ELEVATION
BARGE 1
2
3
4
5
6
7
8
9
1+00
1+41.5
4+34
℄ PORTS
7+26.5
7+70
195'
195'
195'
9' DRAFT
35-FT-WIDE BARGES



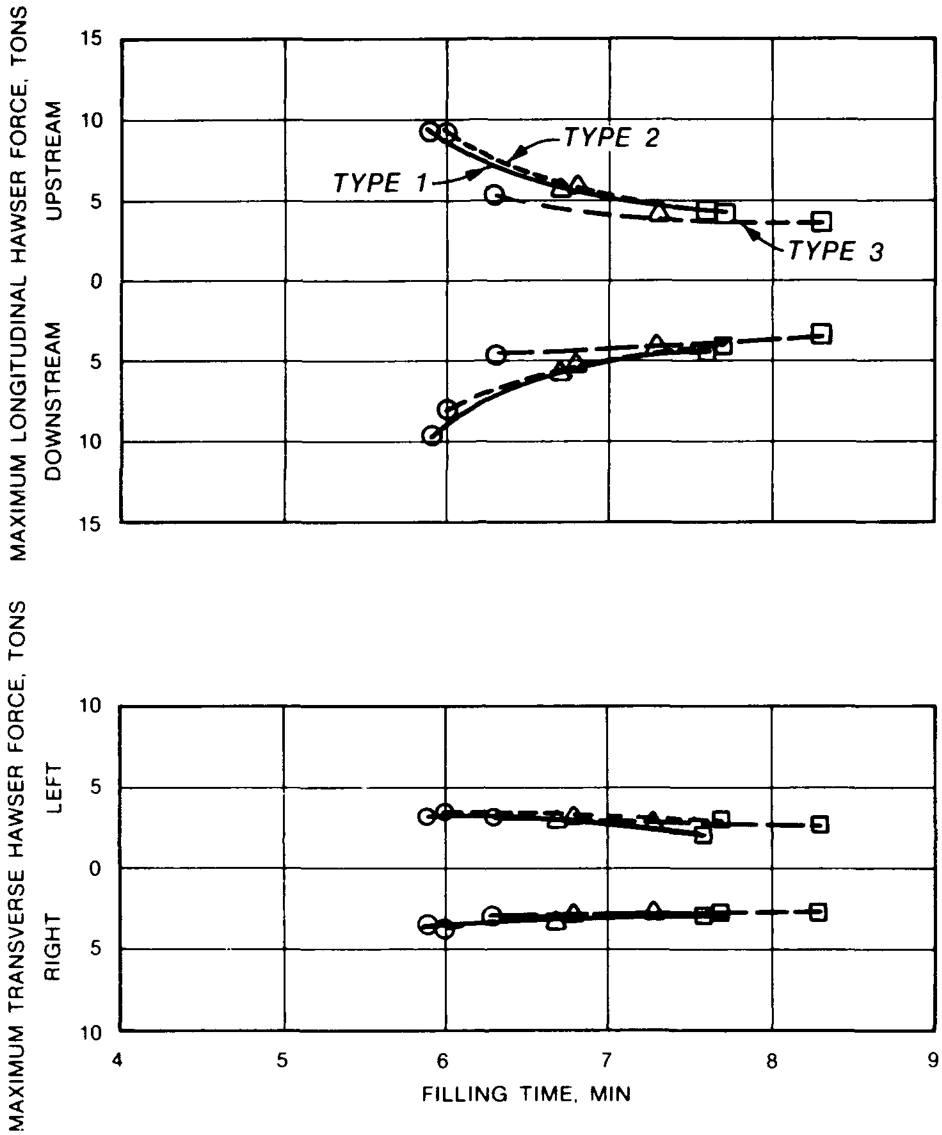
MISSOURI LOCK WALL
PLAN AT EL 385.00

LEGEND

SECOND PLACEMENT CONCRETE

SLIDE GATE SLOT

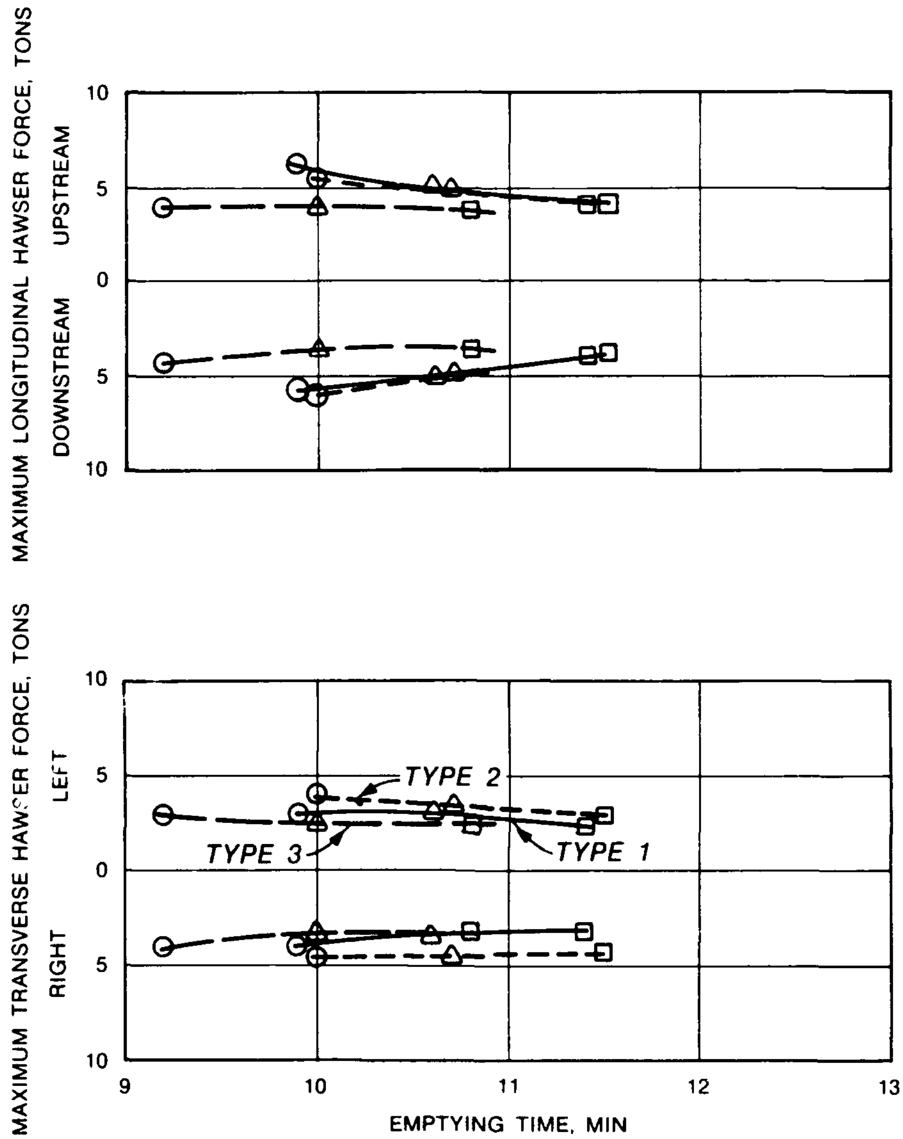
VALVE MONOLITH
WITH SLIDE GATES



LEGEND	
SYMBOL	VALVE TIME, MIN
O	2
Δ	4
□	6

NOTE: UPPER POOL EL 419.0
LOWER POOL EL 403.0

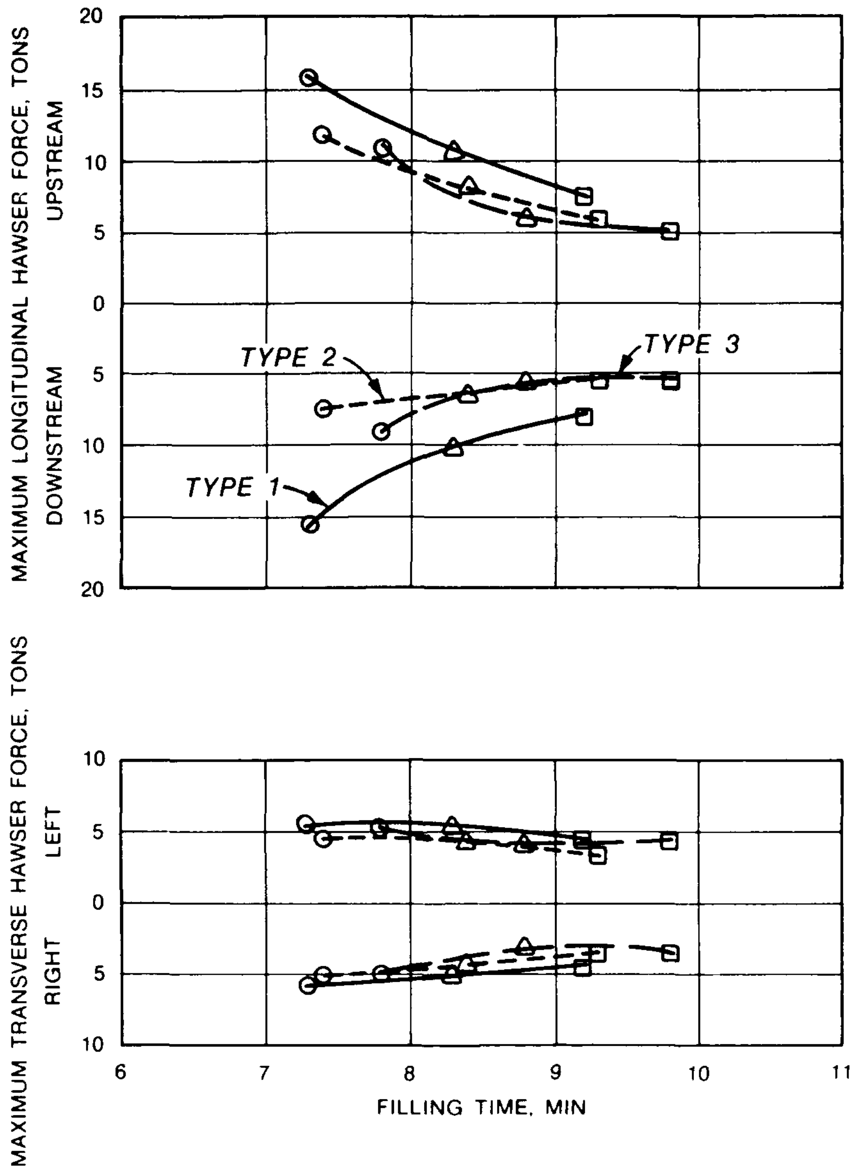
MAXIMUM HAWSER FORCES DURING FILLING OPERATIONS
TYPES 1, 2, AND 3 DESIGN
FILLING AND EMPTYING SYSTEMS
NORMAL VALVE OPERATIONS
16-FT LIFT



LEGEND	
SYMBOL	VALVE TIME, MIN
O	2
Δ	4
□	6

NOTE: UPPER POOL EL 419.0
LOWER POOL EL 403.0

MAXIMUM HAWSER FORCES DURING
EMPTYING OPERATIONS
TYPES 1, 2, AND 3 DESIGN
FILLING AND EMPTYING SYSTEMS
NORMAL VALVE OPERATIONS
16-FT LIFT

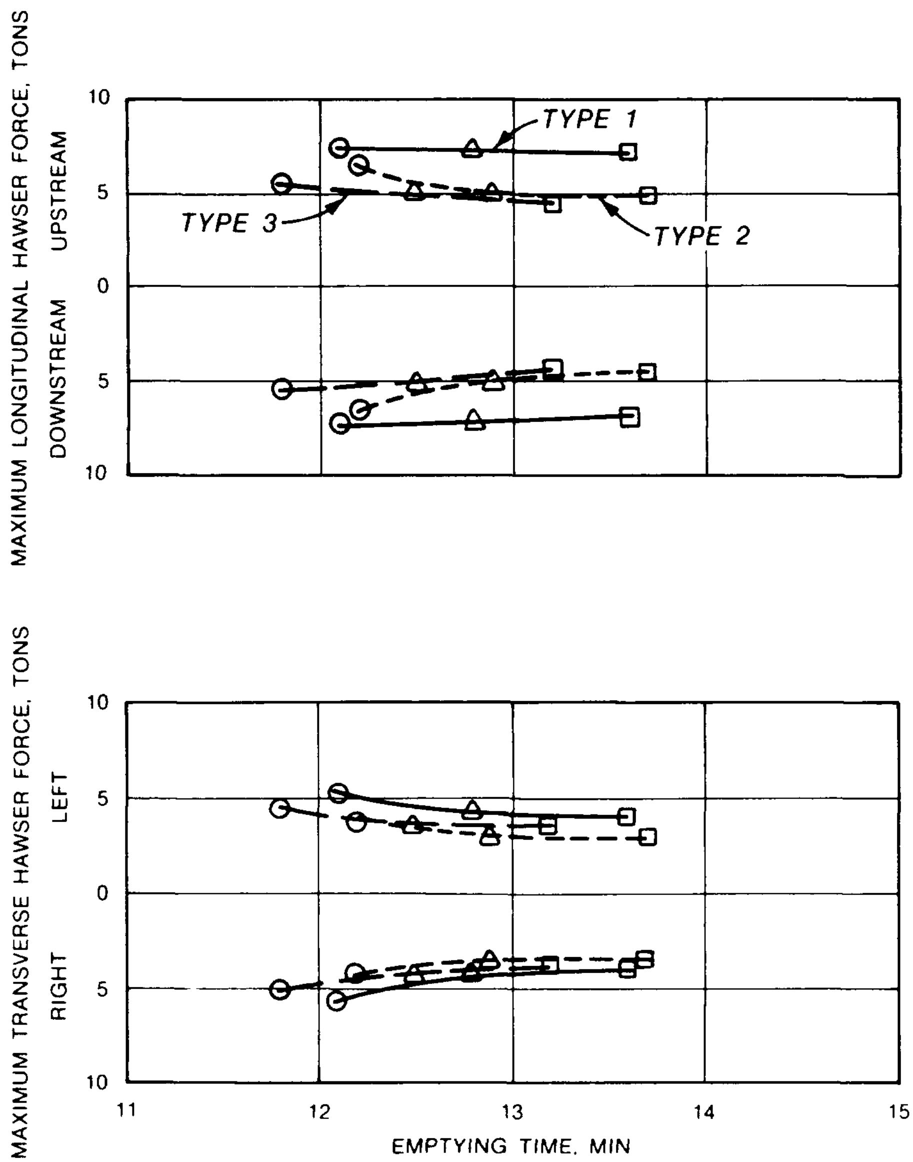


LEGEND	
SYMBOL	VALVE TIME, MIN
○	2
△	4
□	6

NOTE UPPER POOL EL 419 0
LOWER POOL EL 395 0

MAXIMUM HAWSER FORCES DURING FILLING OPERATIONS

TYPES 1, 2, AND 3 DESIGN
FILLING AND EMPTYING SYSTEMS
NORMAL VALVE OPERATIONS
24-FT LIFT

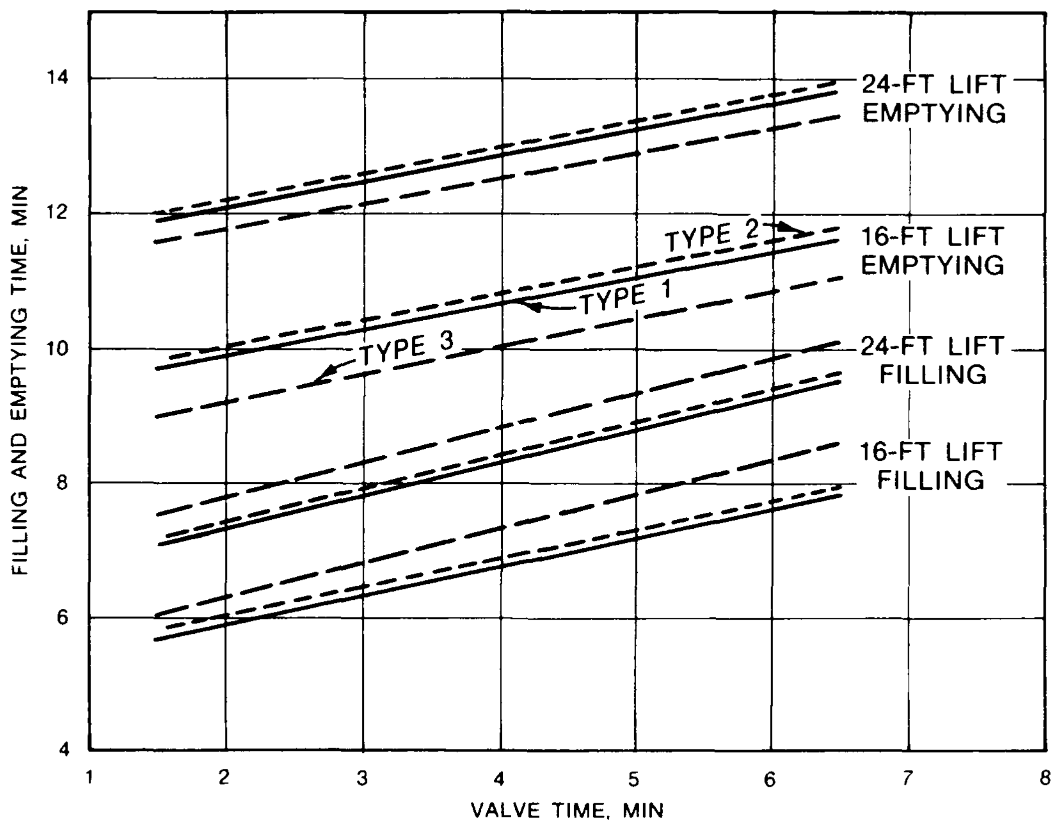


LEGEND	
SYMBOL	VALVE TIME, MIN
○	2
△	4
□	6

NOTE: UPPER POOL EL 419.0
LOWER POOL EL 395.0

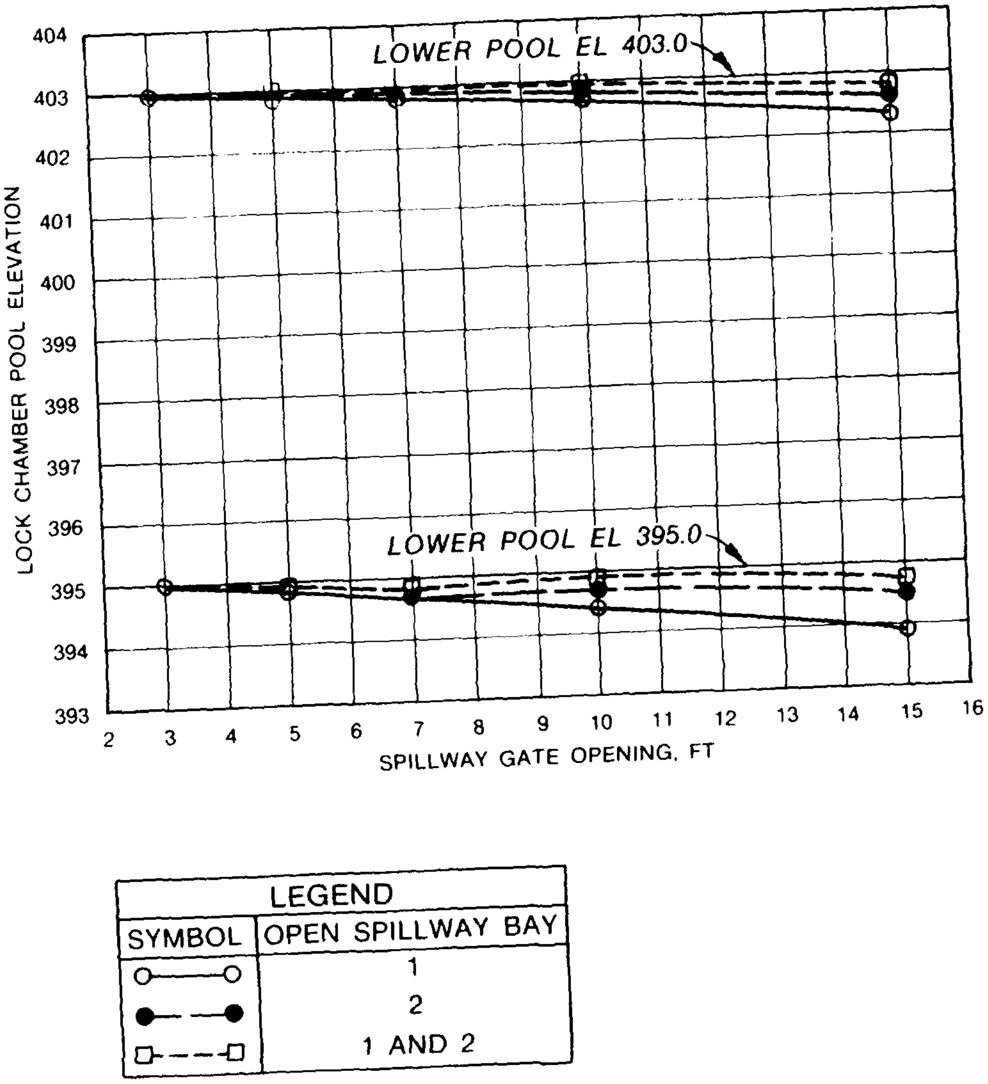
MAXIMUM HAWSER FORCES DURING EMPTYING OPERATIONS

TYPES 1, 2, AND 3 DESIGN
FILLING AND EMPTYING SYSTEMS
NORMAL VALVE OPERATIONS
24-FT LIFT



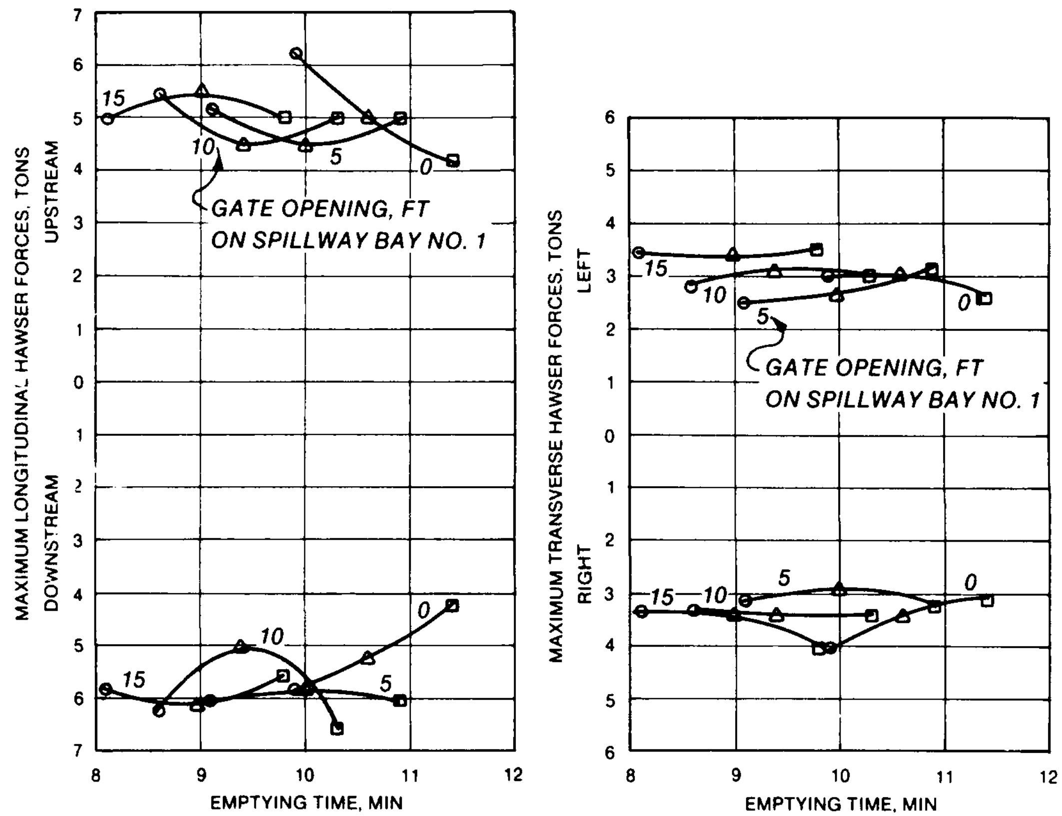
FILLING AND EMPTYING TIMES VERSUS VALVE TIMES

TYPES 1, 2, AND 3 DESIGN
FILLING AND EMPYTING SYSTEMS
NORMAL VALVE OPERATIONS



NOTE: LOCK CHAMBER POOL ELEVATION AFTER NORMAL EMPYTING OPERATION (BOTH EMPTYING VALVES OPEN), UPPER POOL EL 419.0. SPILLWAY BAY 1 IS ADJACENT TO THE AUXILIARY LOCK.

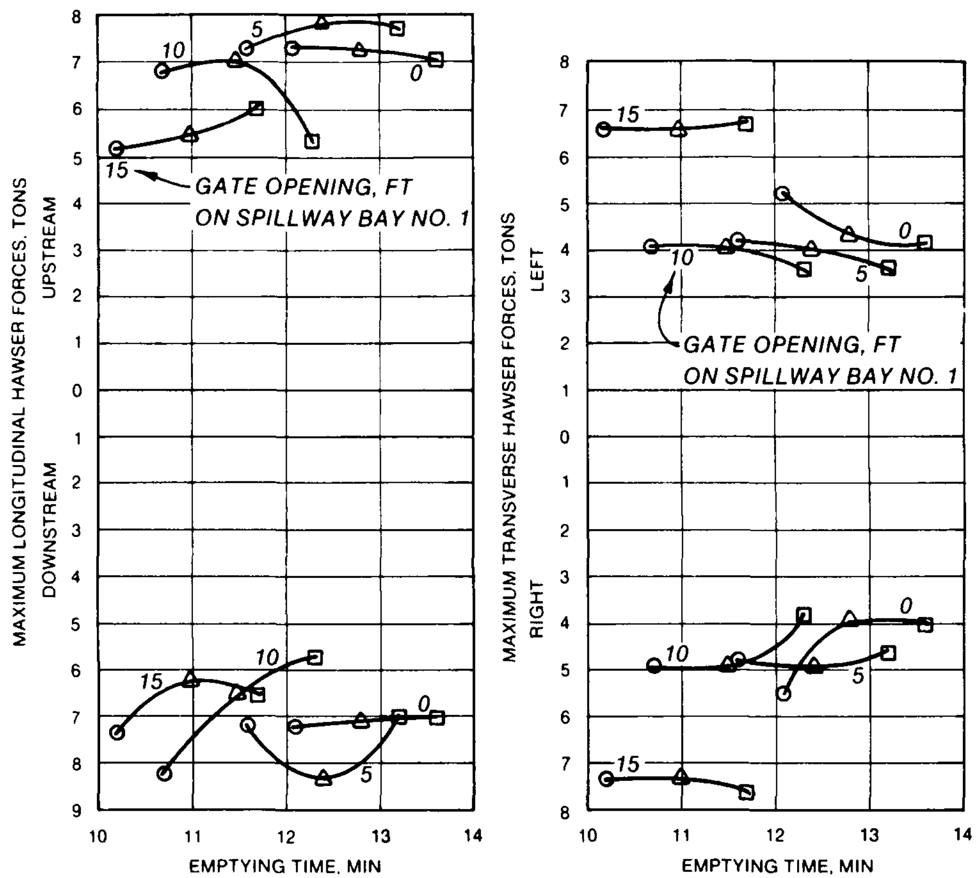
LOCK CHAMBER POOL ELEVATION
VERSUS SPILLWAY GATE OPENING



LEGEND	
SYMBOL	VALVE TIME, MIN
○	2
△	4
□	6

NOTE: UPPER POOL EL 419.0
LOWER POOL EL 403.0

MAXIMUM HAWSER FORCES
DURING EMPTYING OPERATIONS
WITH SPILLWAY FLOW VARIED
TYPE 1 (ORIGINAL) DESIGN
NORMAL VALVE OPERATION
16-FT LIFT

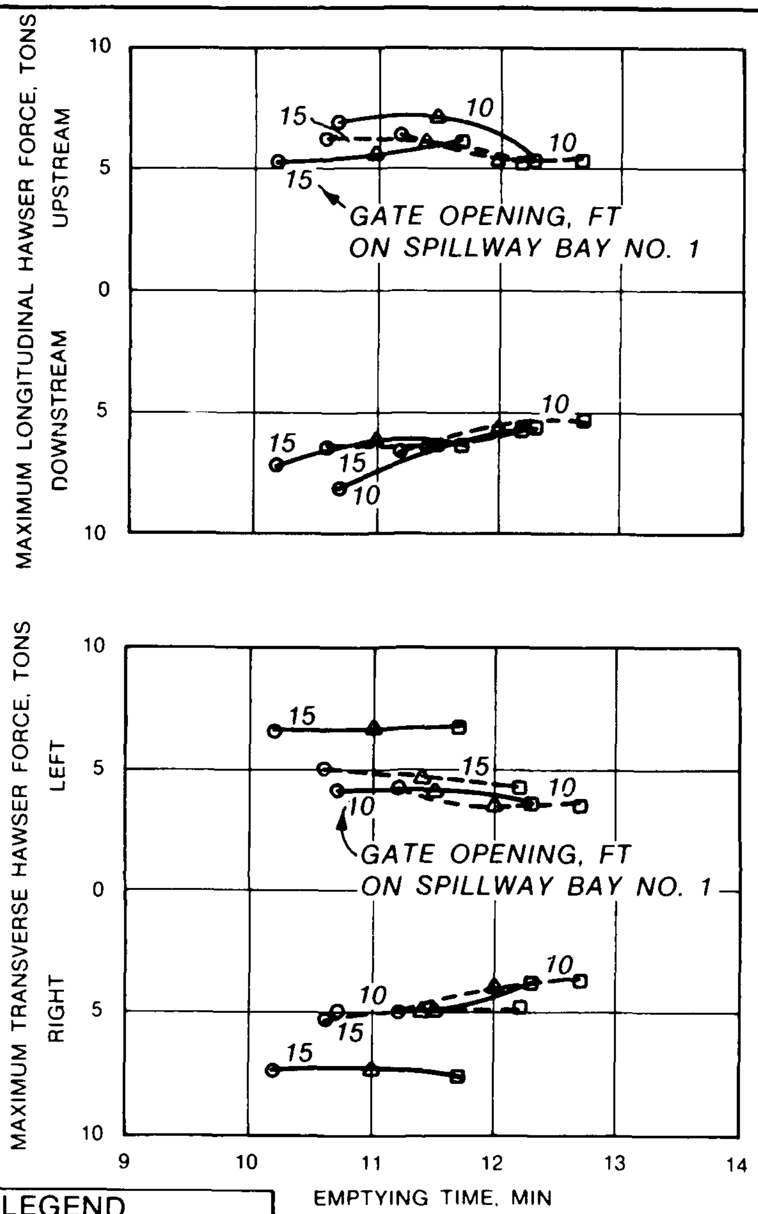


LEGEND	
SYMBOL	VALVE TIME, MIN
○	2
△	4
□	6

NOTE UPPER POOL EL 419.0
LOWER POOL EL 395.0

MAXIMUM HAWSER FORCES
DURING EMPTYING OPERATIONS
WITH SPILLWAY FLOW VARIED

TYPE 1 (ORIGINAL) DESIGN
NORMAL VALVE OPERATIONS
24-FT LIFT



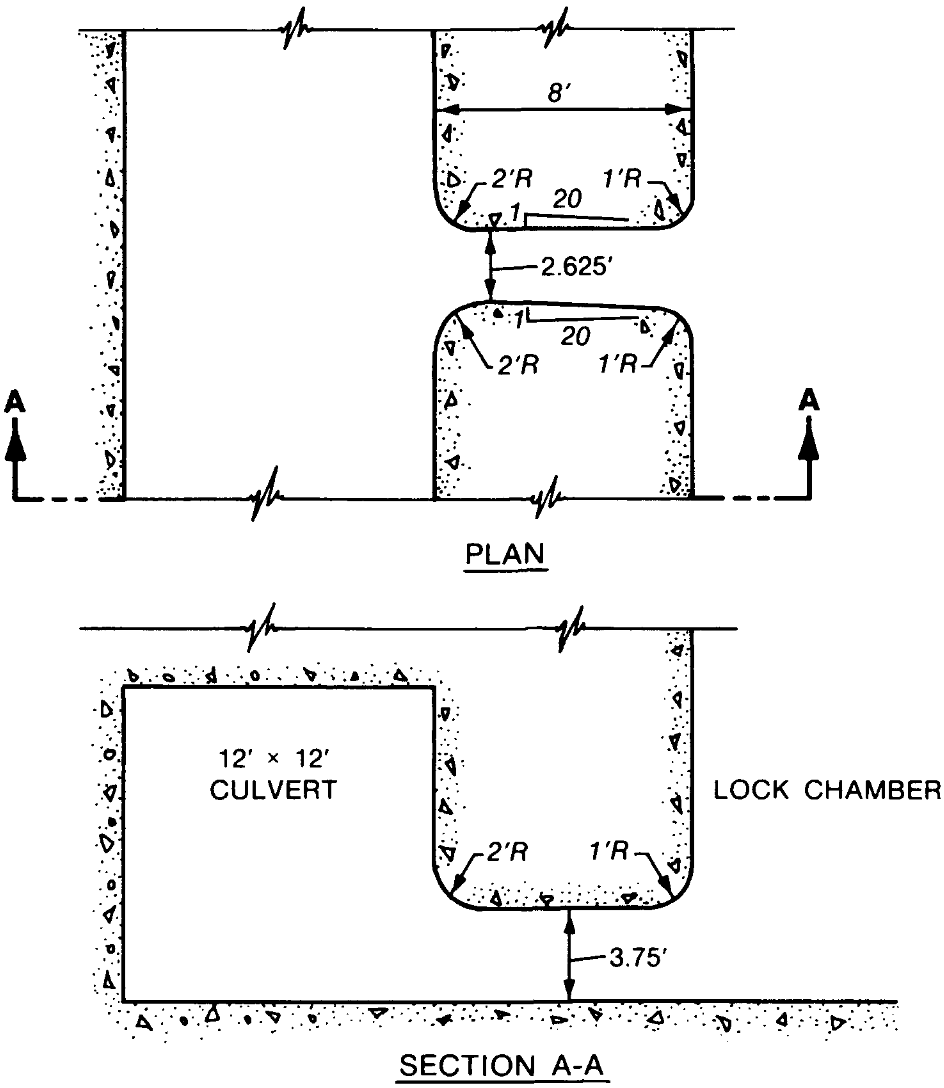
LEGEND	
—— NORMAL VALVE SCHEDULE	
- - - - MODIFIED VALVE SCHEDULE	
SYMBOL	VALVE TIME, MIN
○	2
△	4
□	6

NOTE: UPPER POOL EL 419.0
LOWER POOL EL 395.0

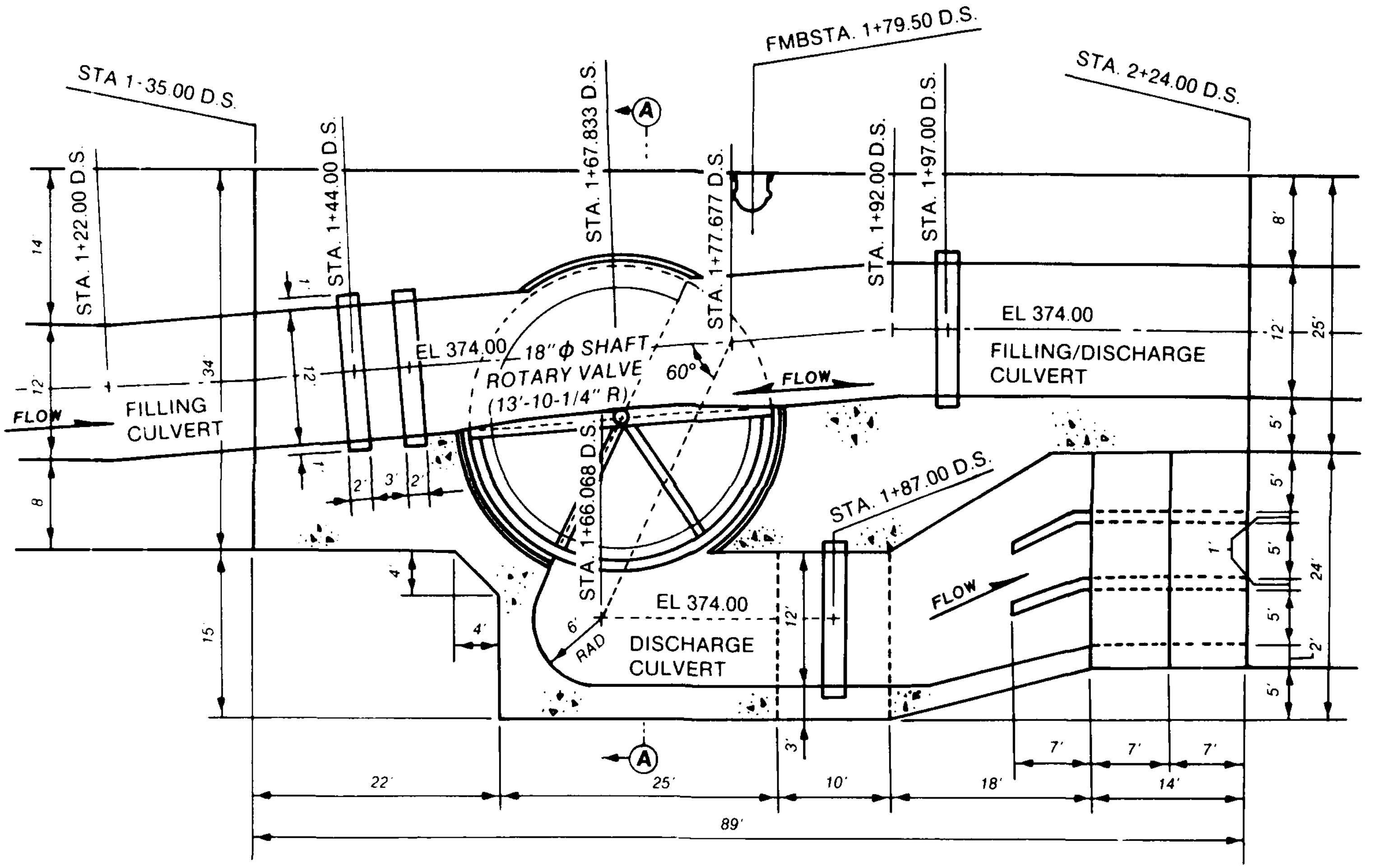
EFFECTS OF MODIFIED VALVE SCHEDULES ON MAXIMUM HAWSER FORCES DURING EMPTYING OPERATIONS WITH SPILLWAY FLOW VARIED

TYPE 1 (ORIGINAL) DESIGN

24-FT LIFT



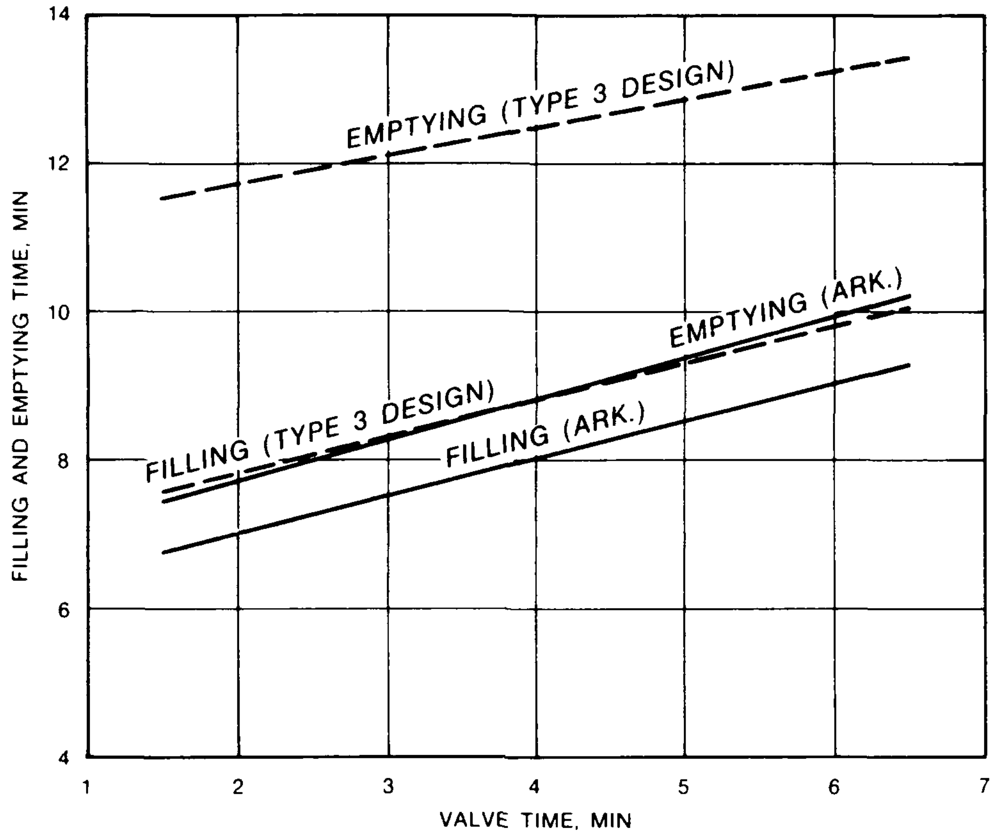
PORT MODIFICATION
TYPE 2 DESIGN FILLING AND
EMPTYING SYSTEM



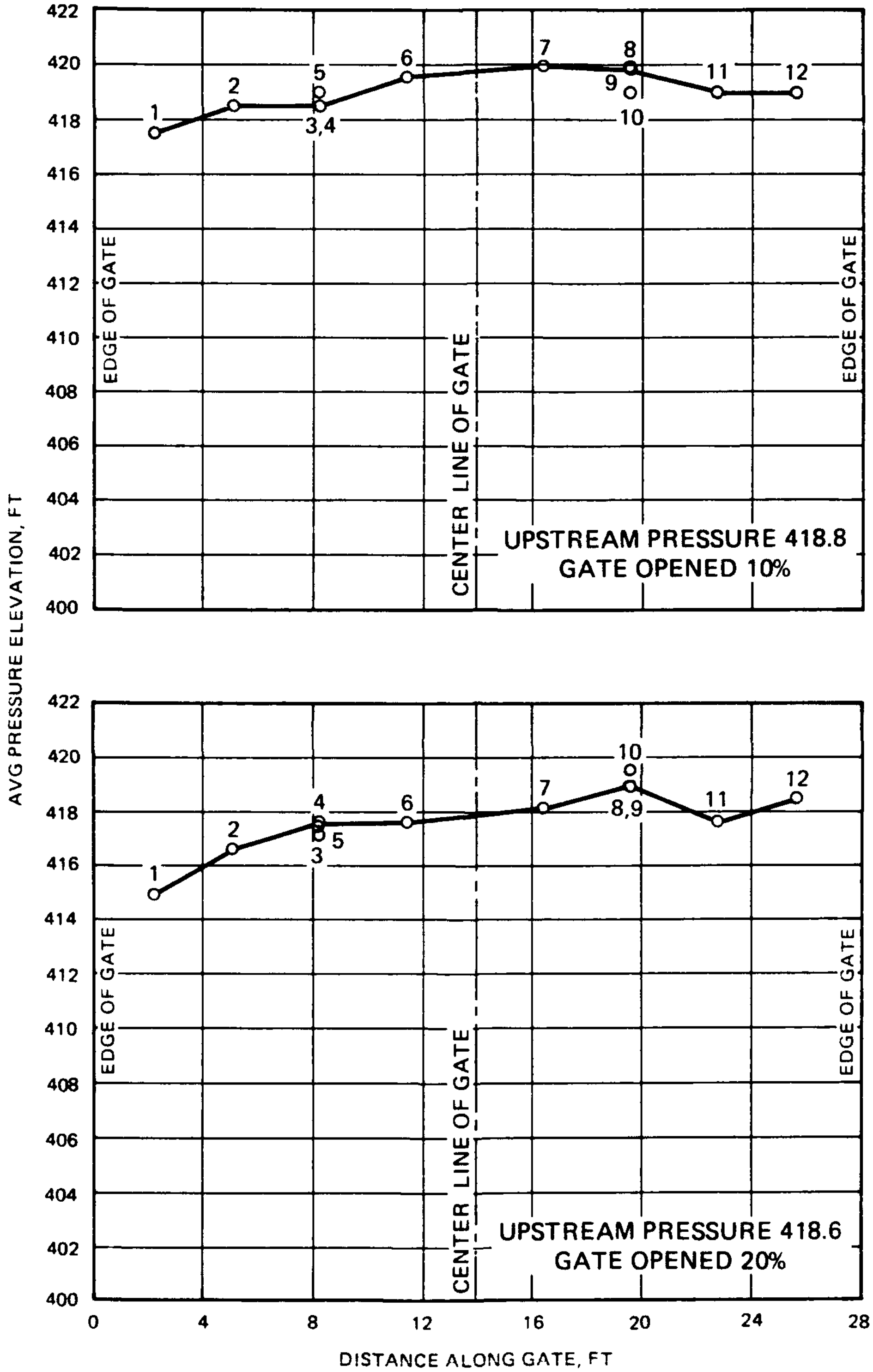
NOTE: VALVE IN FILL POSITION

MISSOURI LOCK WALL
PLAN AT EL 385.00

VALVE MONOLITH
WITH ROTARY VALVE

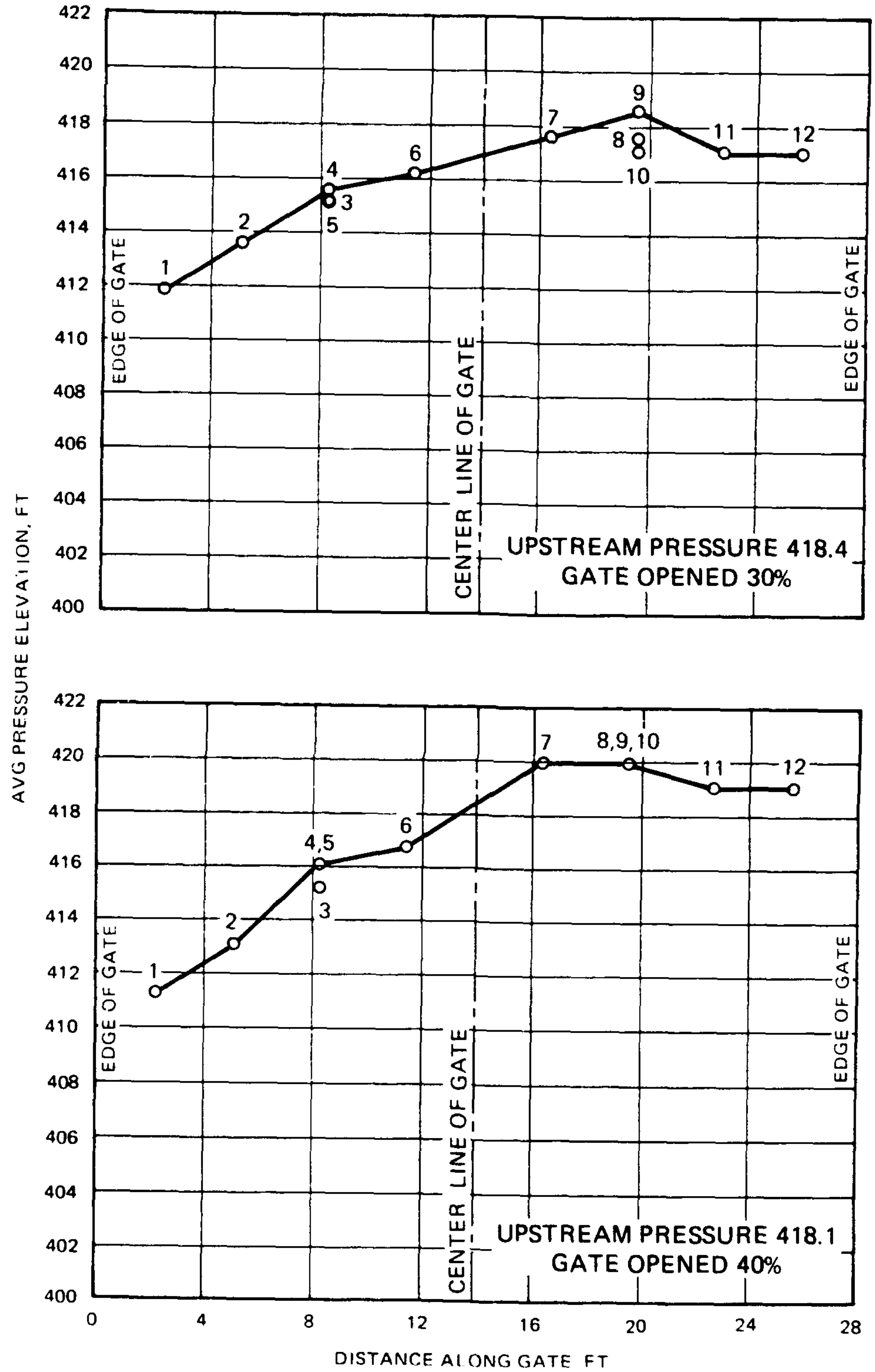


FILLING AND EMPTYING TIMES
VERSUS VALVE TIMES
COMPARISON OF TYPE 3 DESIGN
WITH CONVENTIONAL SYSTEM
NORMAL VALVE OPERATIONS
24-LIFT



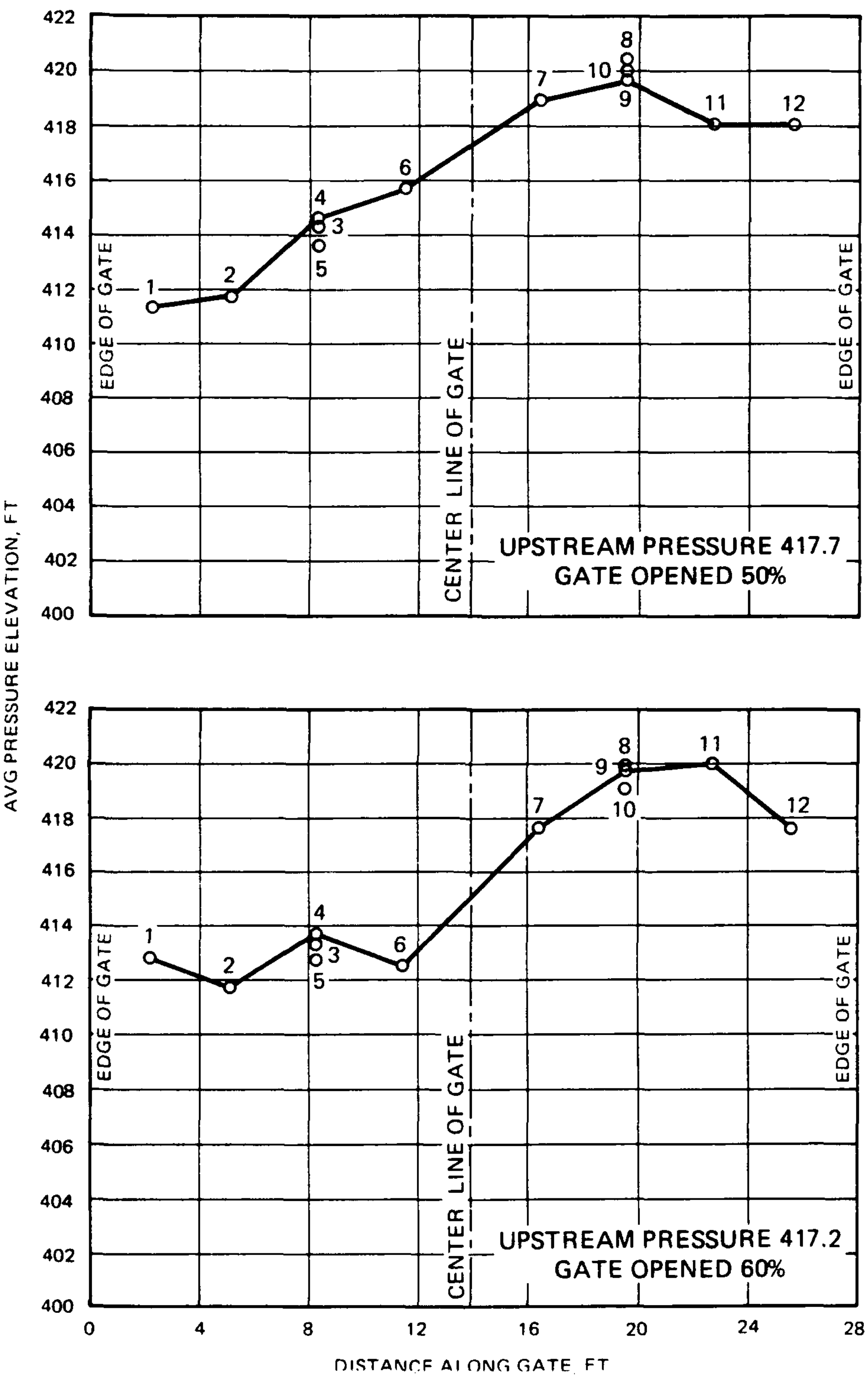
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 403.0
GATE OPENED 10 AND 20 PERCENT



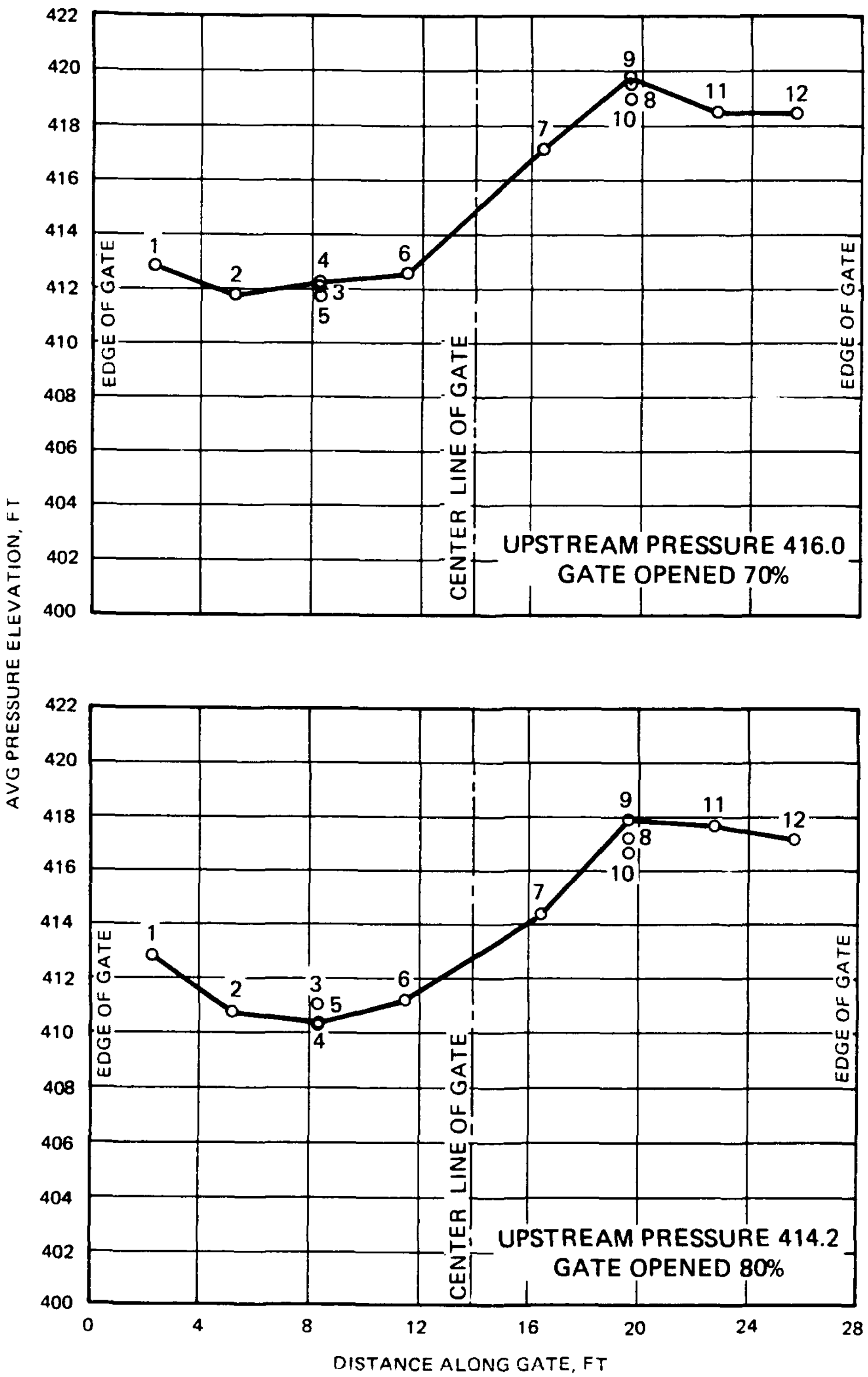
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 403.0
GATE OPENED 30 AND 40 PERCENT



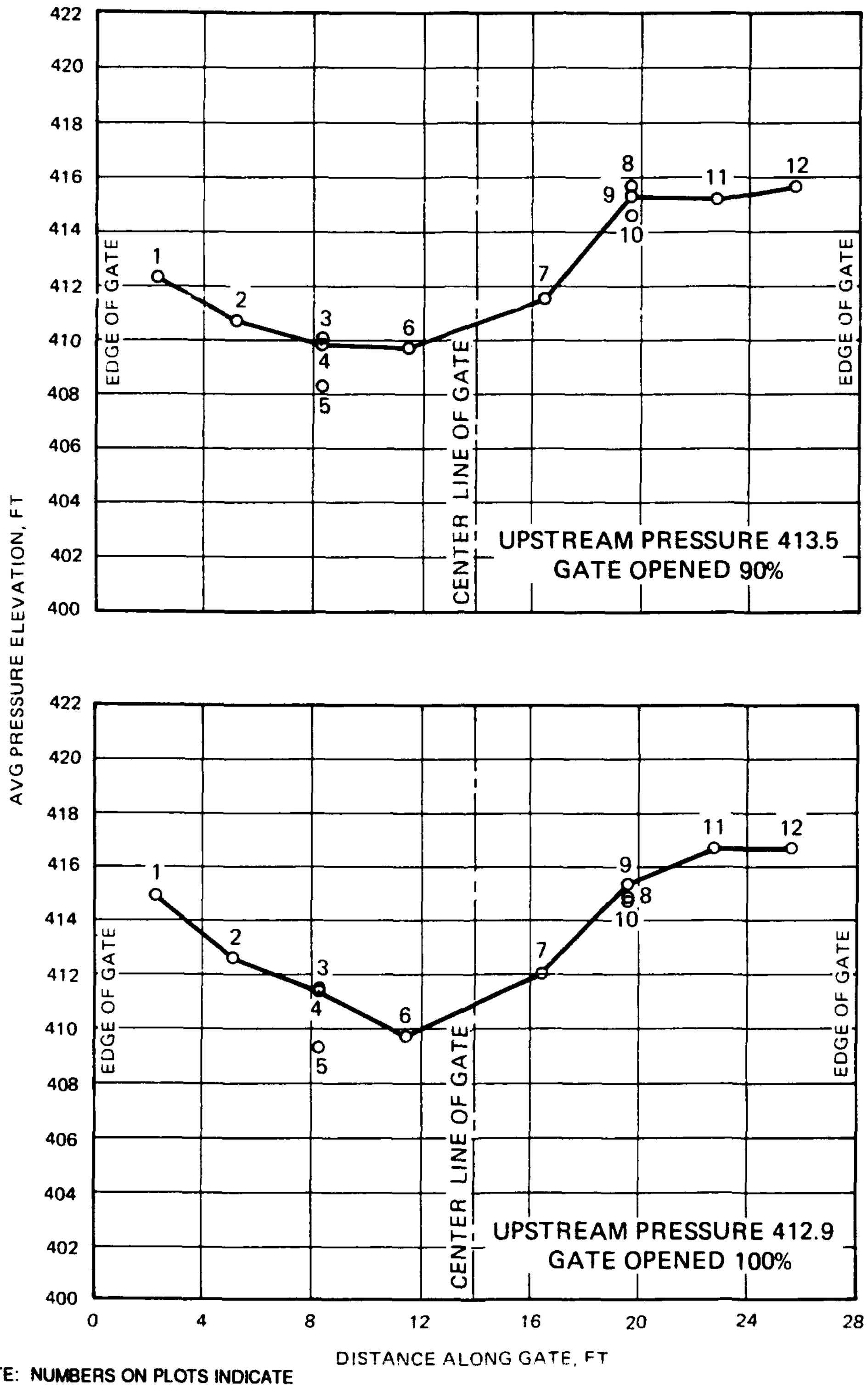
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 403.0
GATE OPENED 50 AND 60 PERCENT



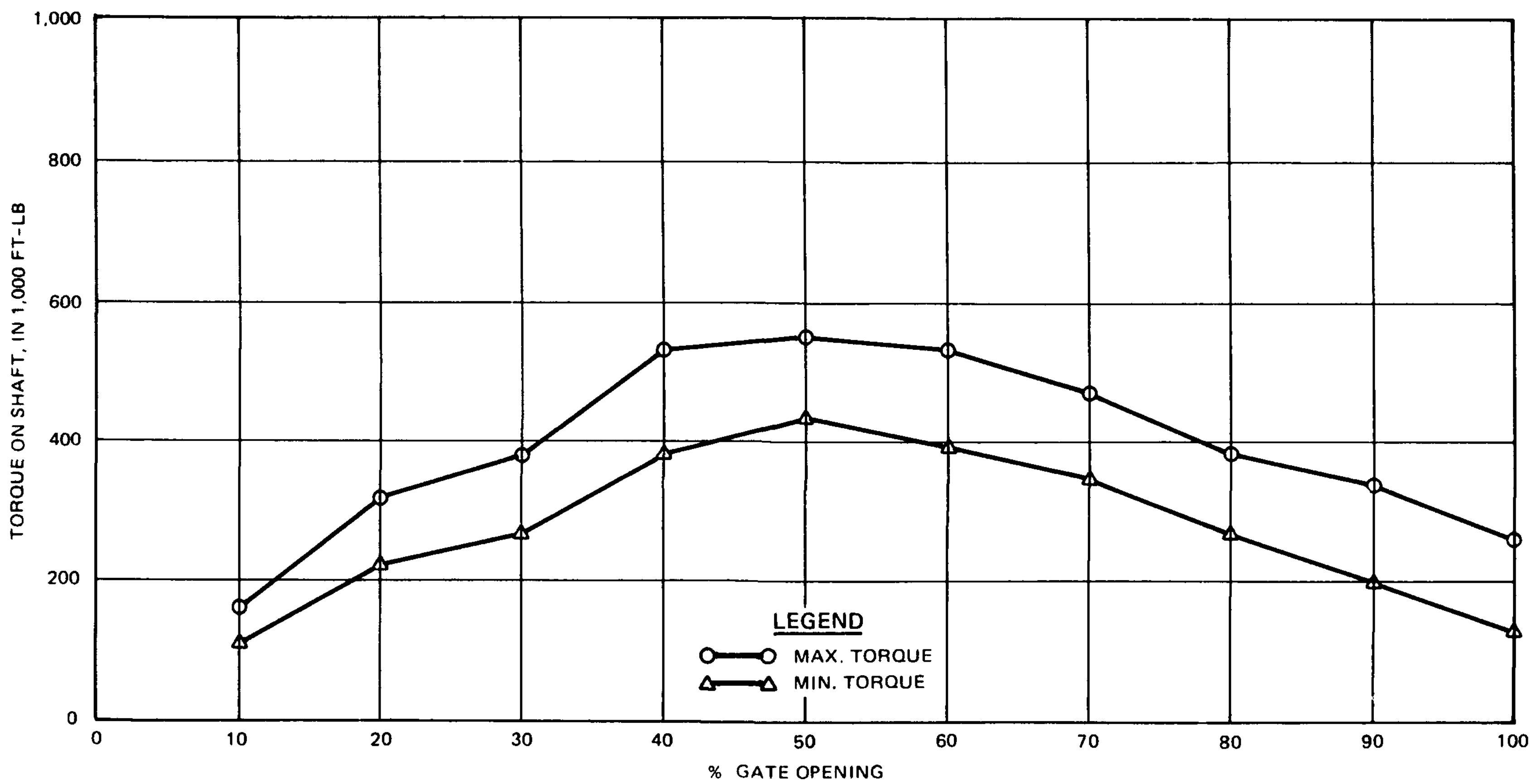
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 403.0
GATE OPENED 70 AND 80 PERCENT

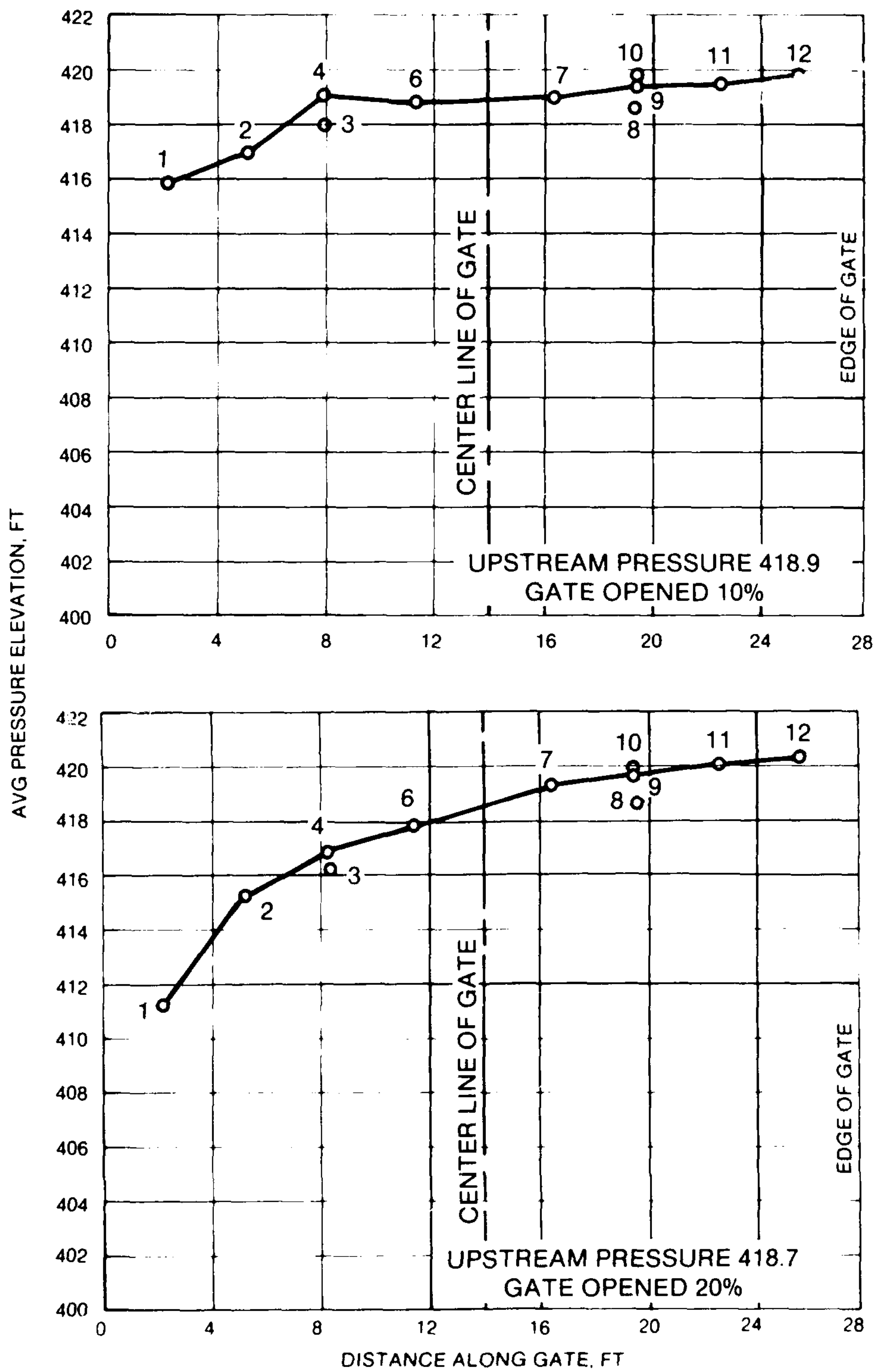


NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 403.0
GATE OPENED 90 AND 100 PERCENT

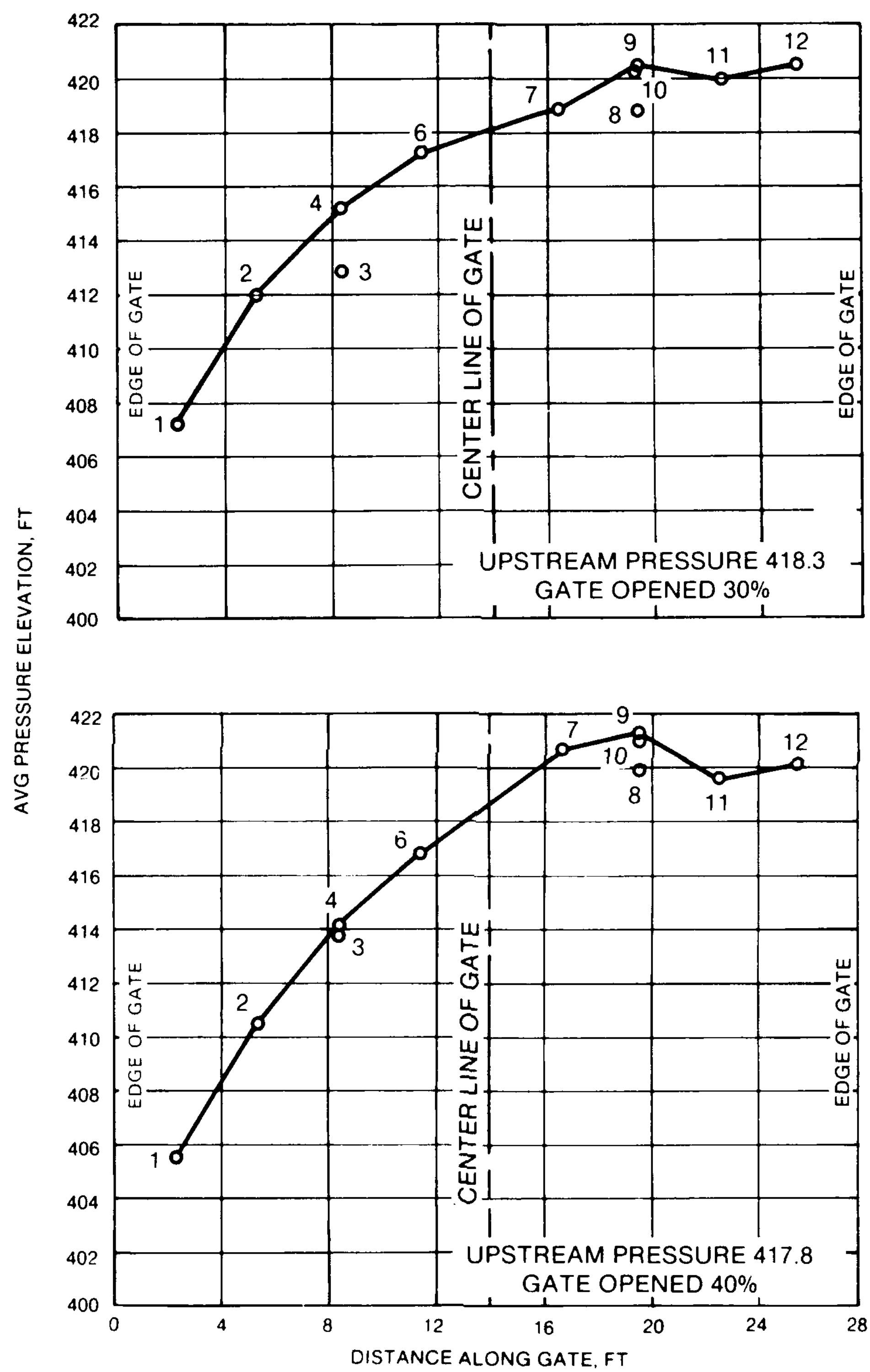


TORQUE VERSUS PERCENT GATE OPENING
TAILWATER EL 403.0



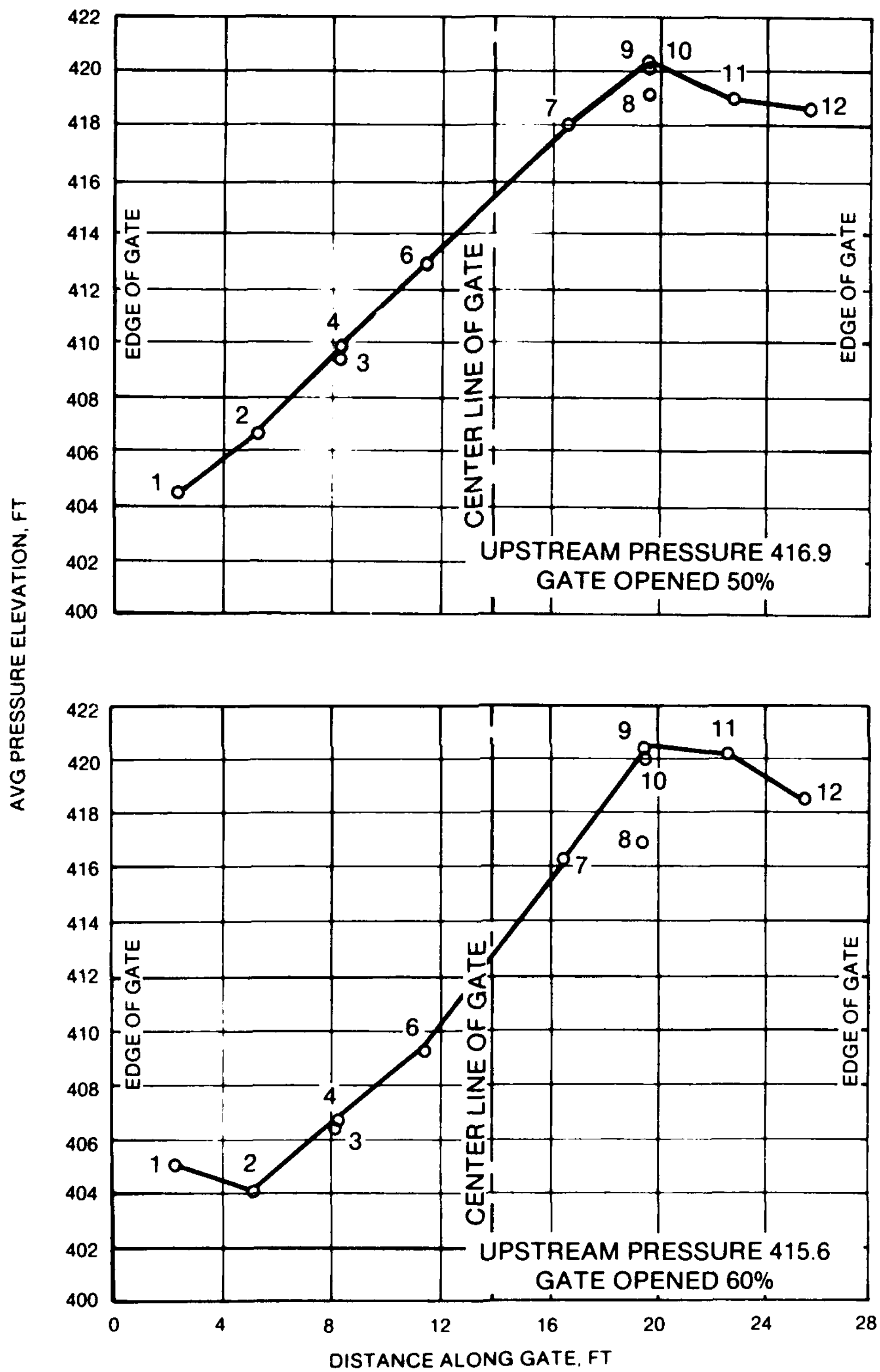
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 395.0
GATE OPENED 10 AND 20 PERCENT



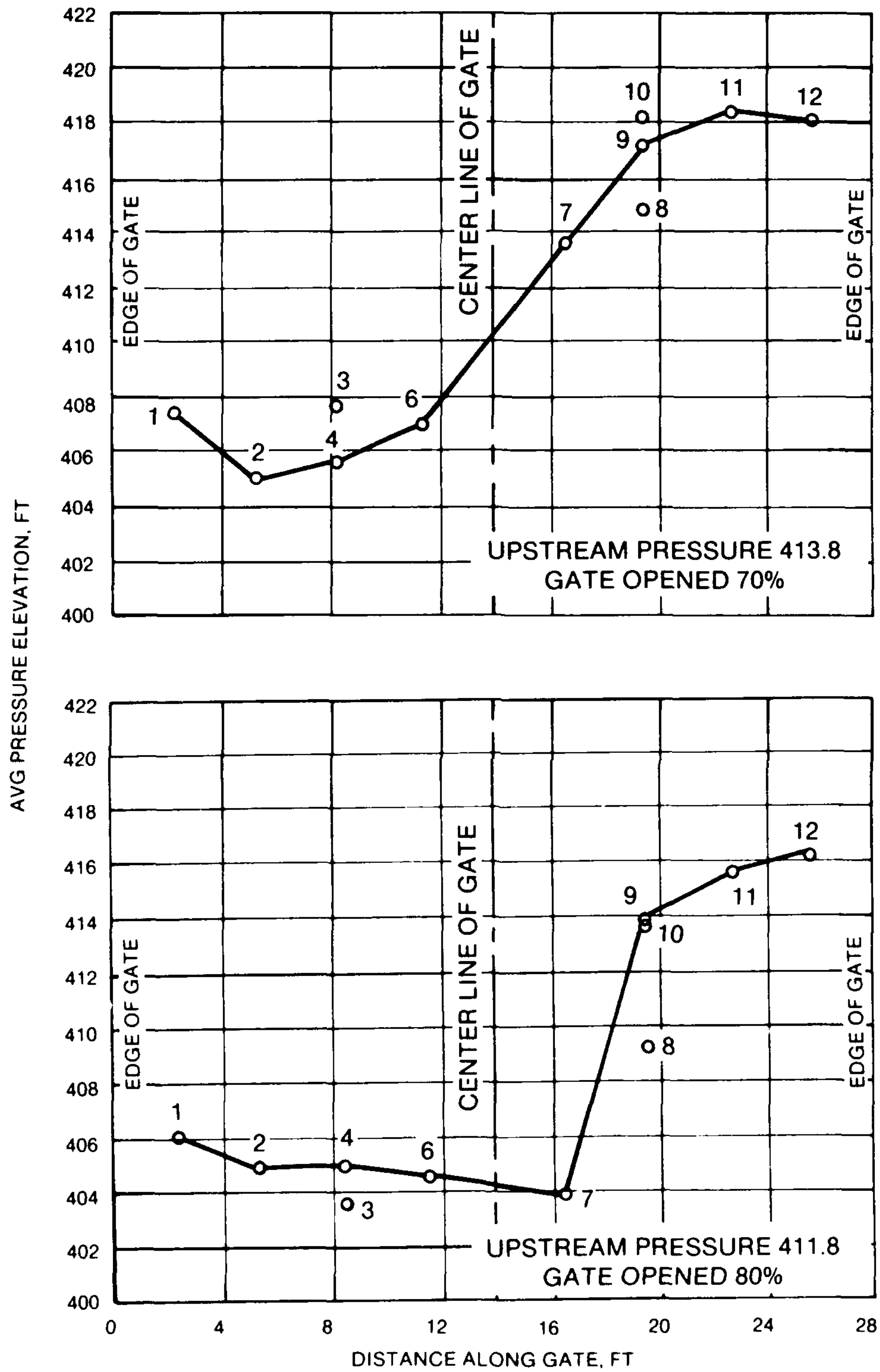
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 395.0
GATE OPENED 30 AND 40 PERCENT



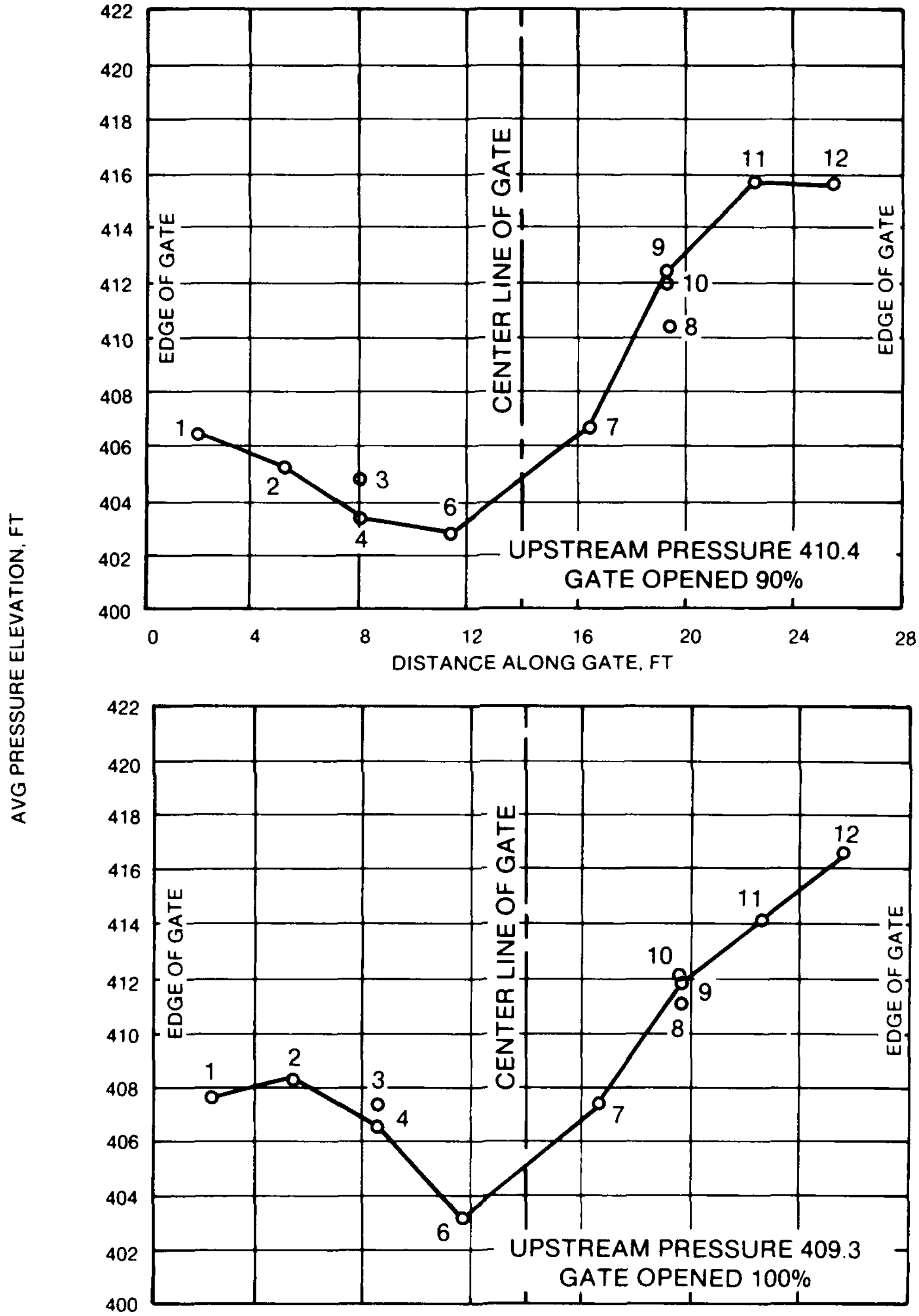
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 395.0
GATE OPENED 50 AND 60 PERCENT



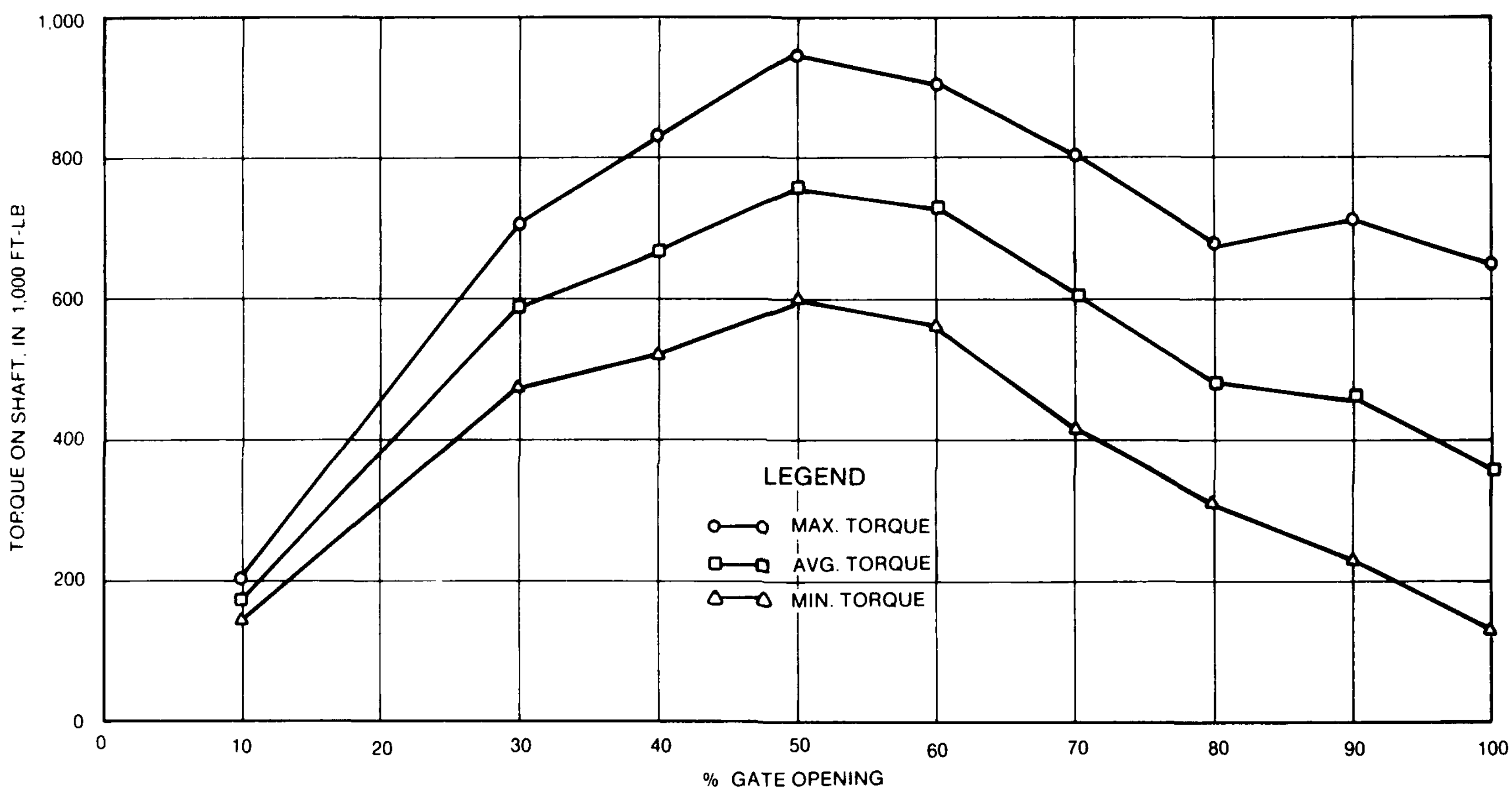
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 395.0
GATE OPENED 70 AND 80 PERCENT

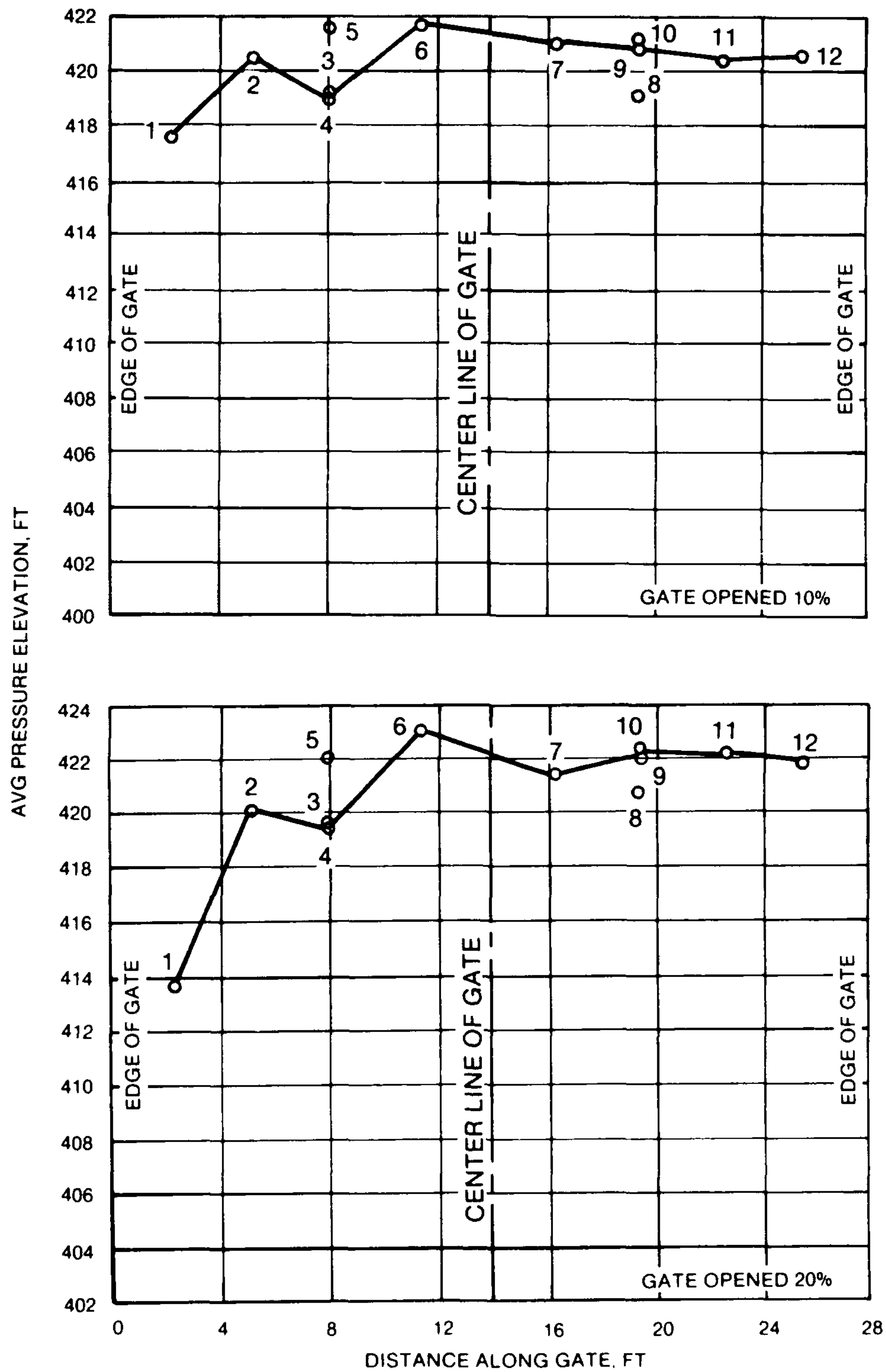


NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
TAILWATER EL 395.0
GATE OPENED 90 AND 100 PERCENT

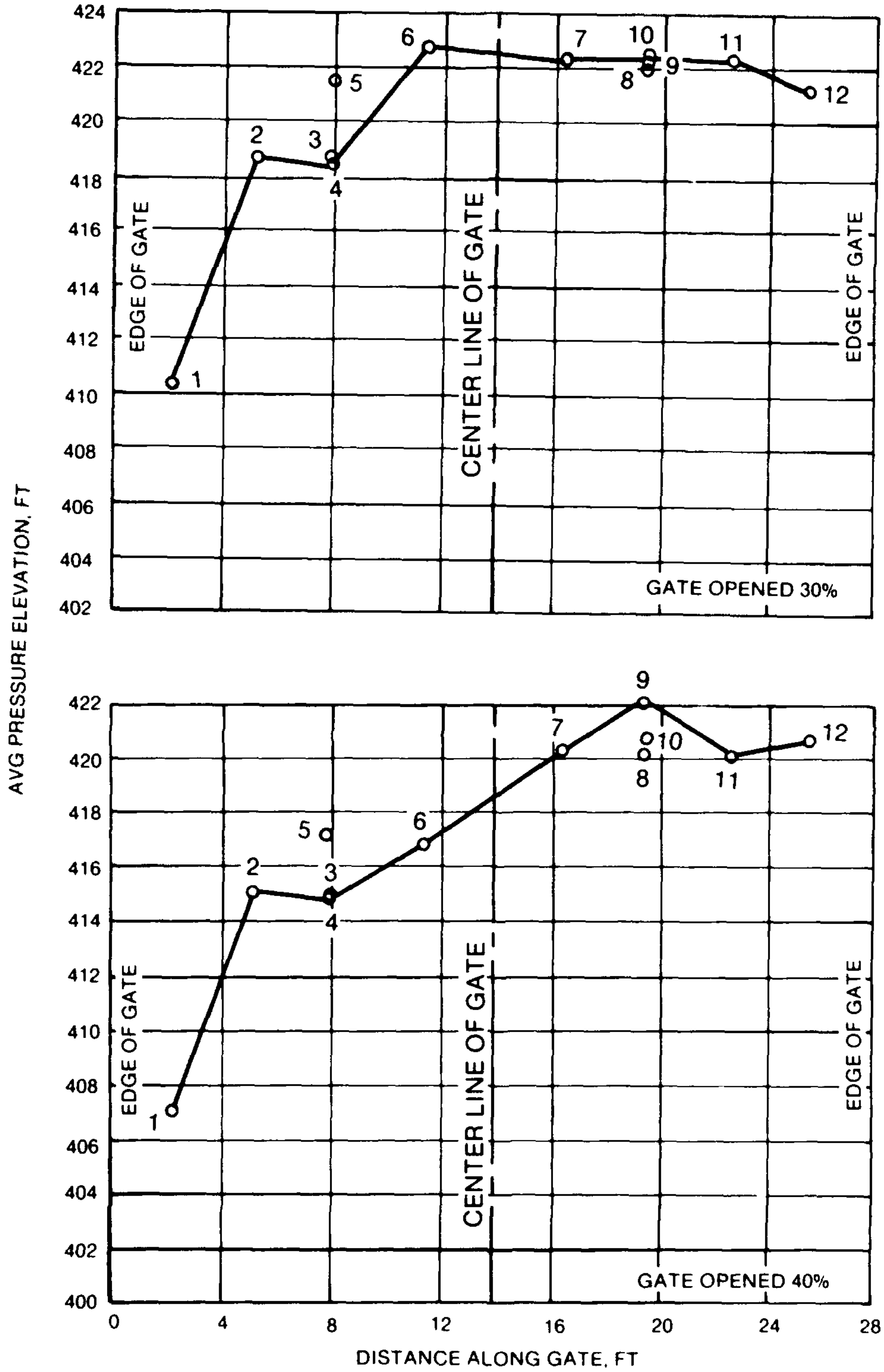


TORQUE VERSUS PERCENT GATE OPENING
TAILWATER EL 395.0



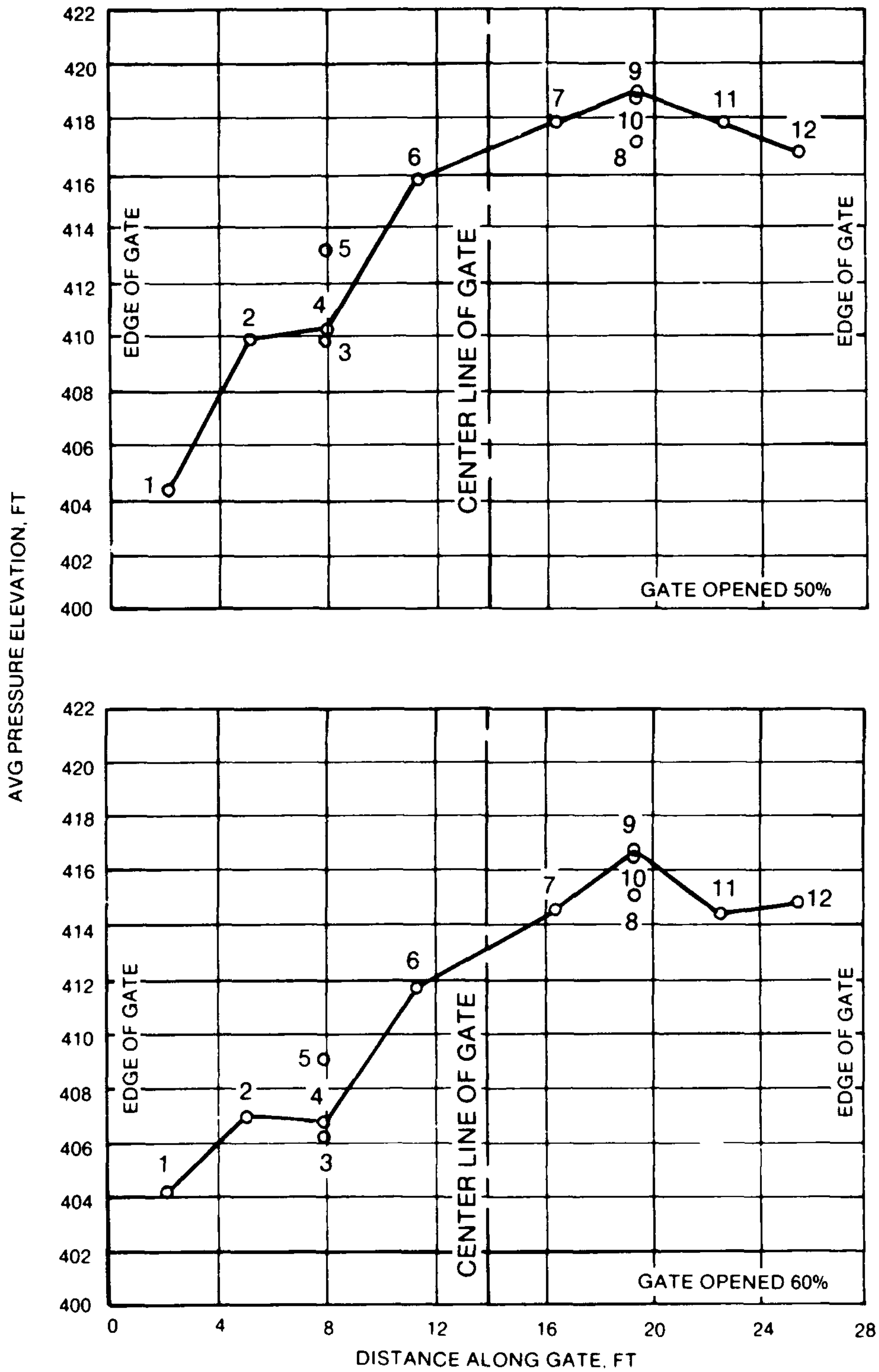
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 10 AND 20 PERCENT



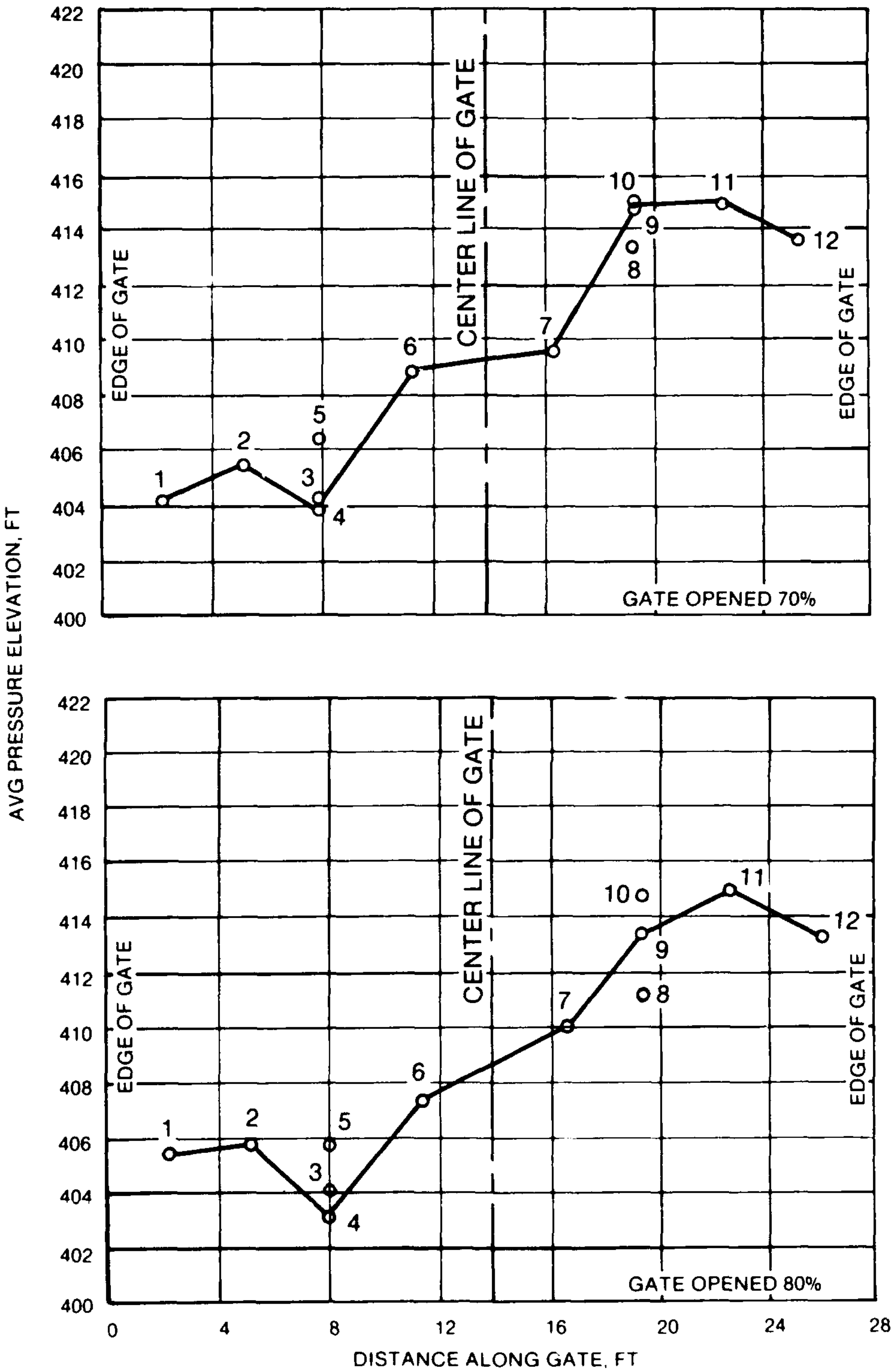
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 30 AND 40 PERCENT



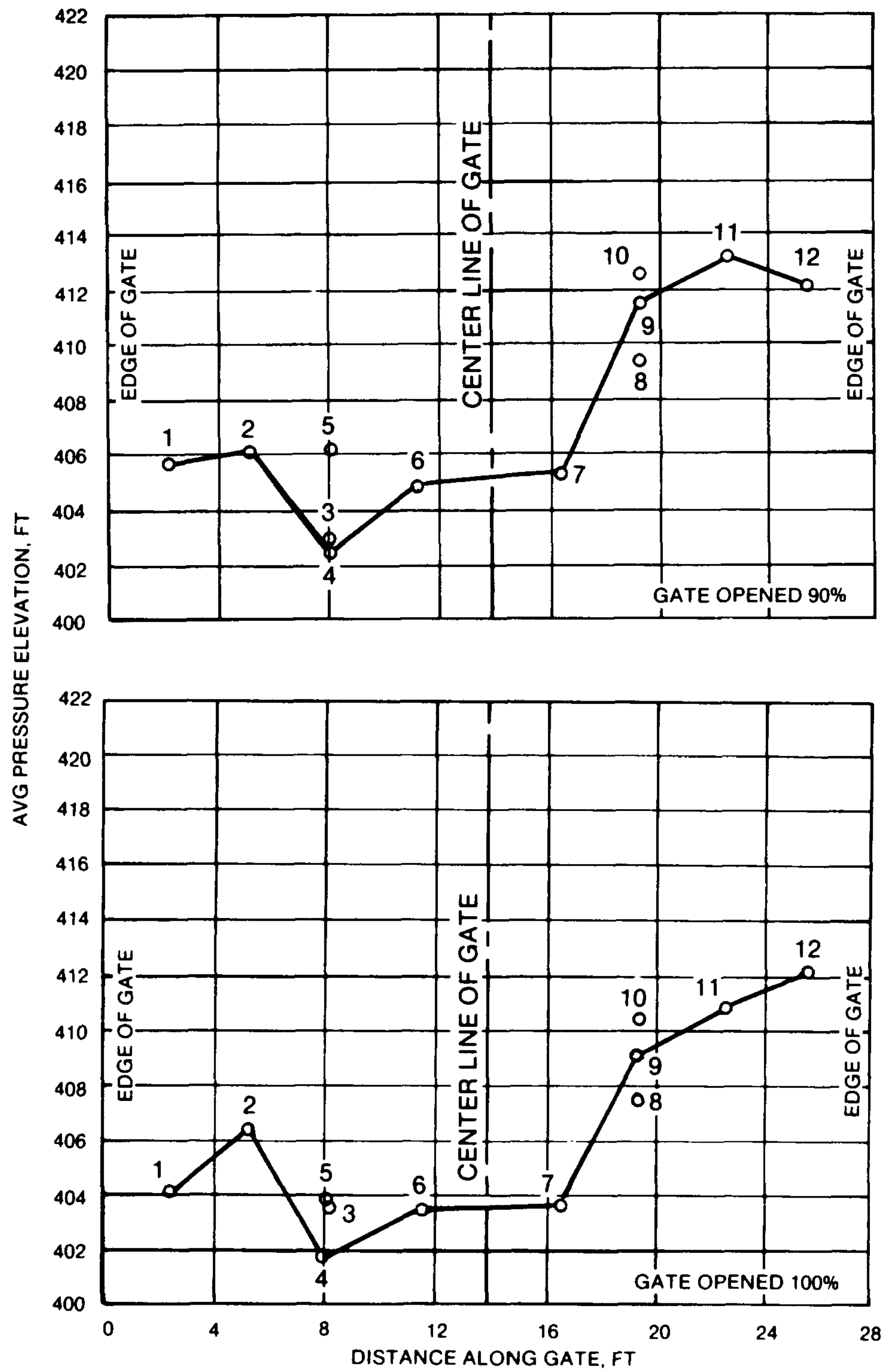
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 50 AND 60 PERCENT



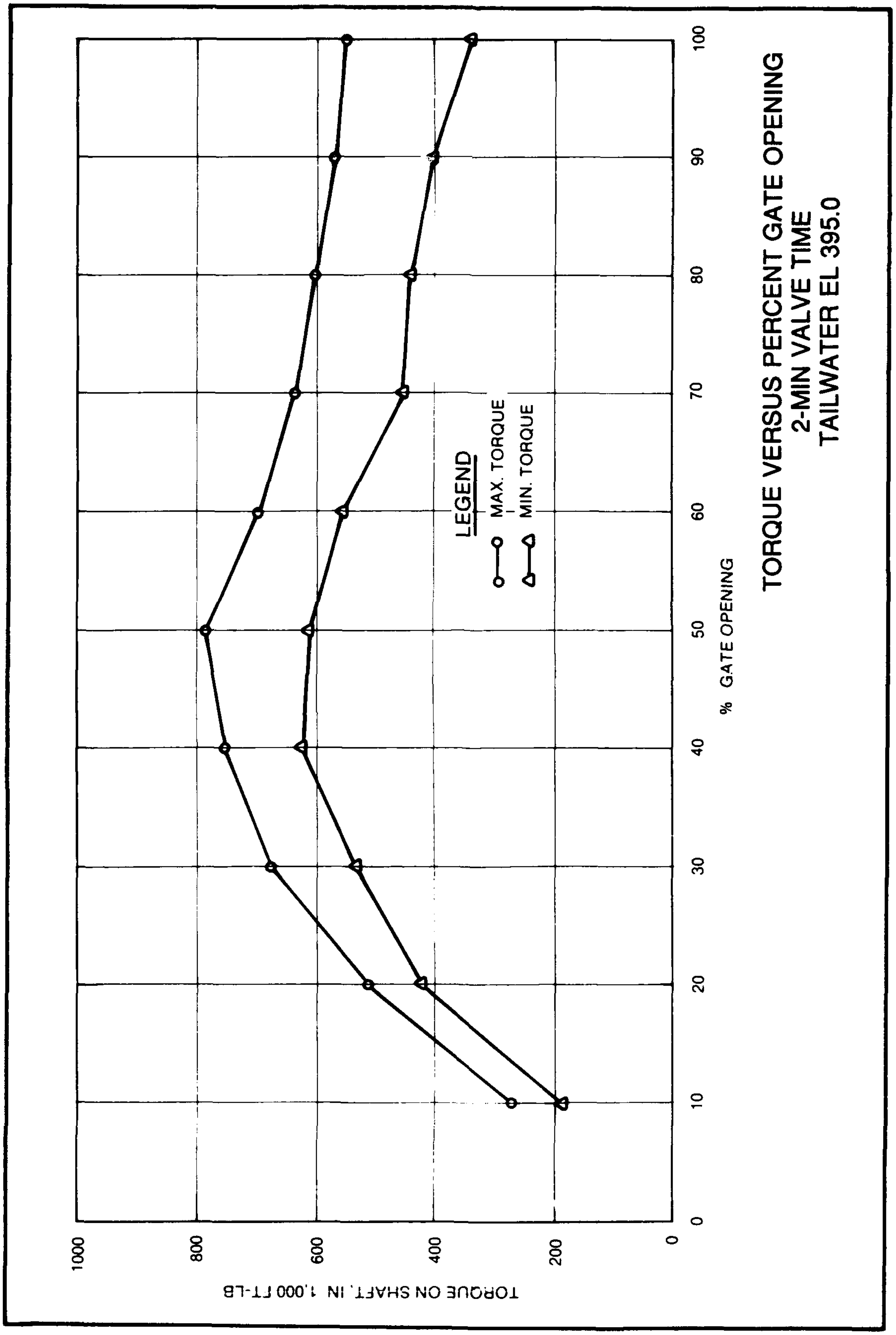
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

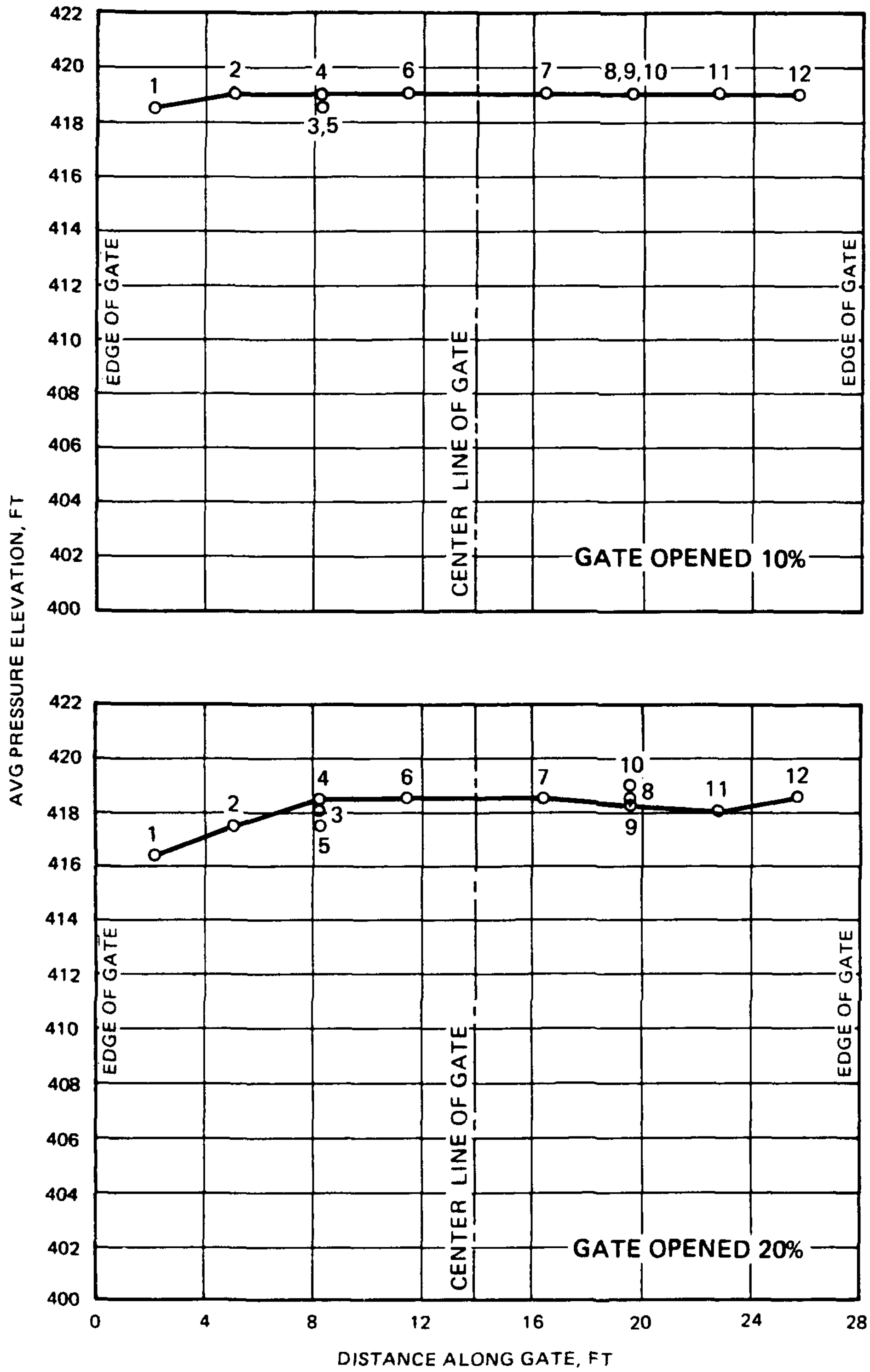
PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 70 AND 80 PERCENT



NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

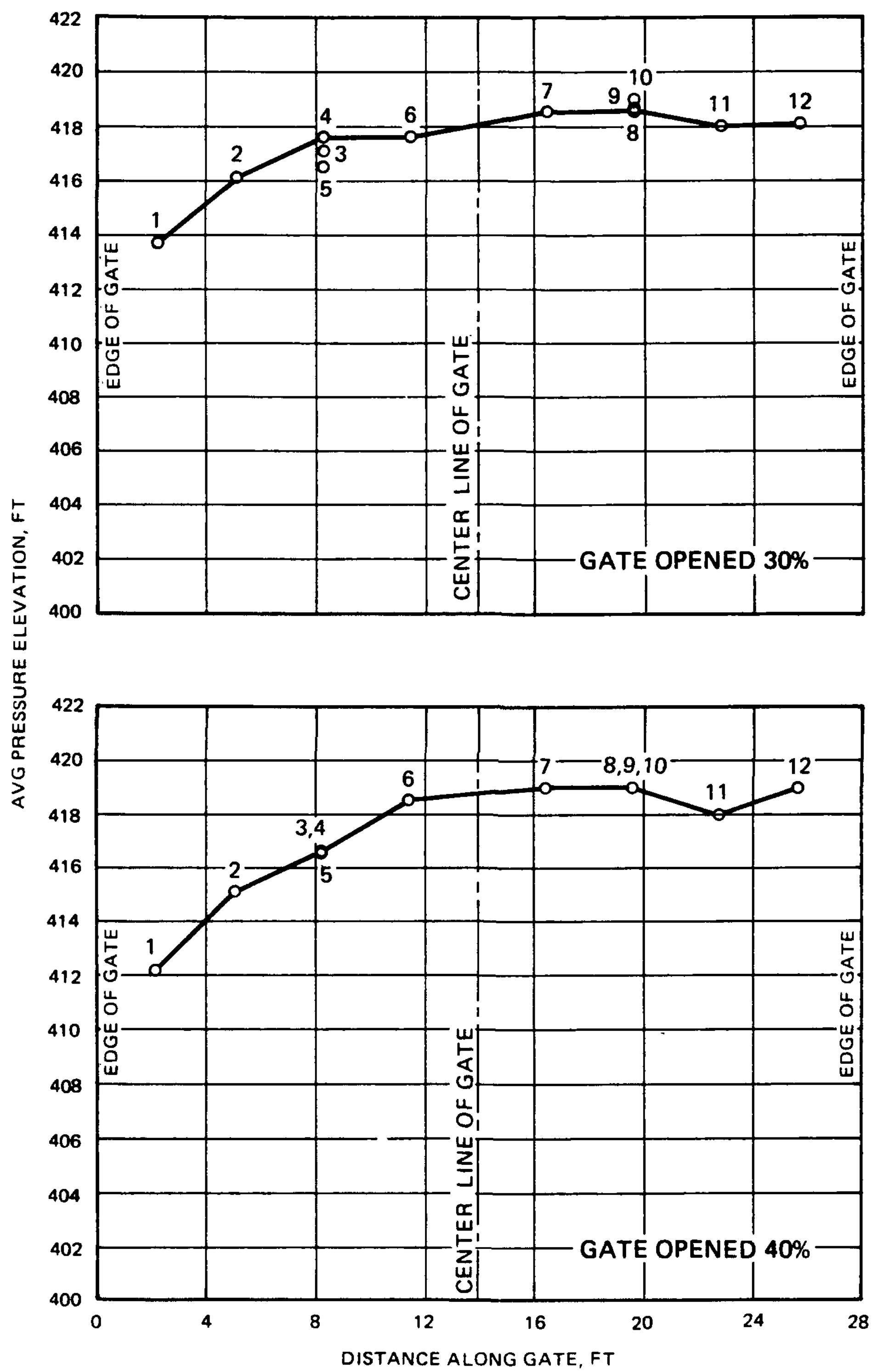
PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 90 AND 100 PERCENT


TORQUE VERSUS PERCENT GATE OPENING
2-MIN VALVE TIME
TAILWATER EL 395.0
LEGEND
MAX. TORQUE
MIN. TORQUE
% GATE OPENING
TORQUE ON SHAFT, IN 1,000 FT-LB
0
10
20
30
40
50
60
70
80
90
100
200
400
600
800
1000



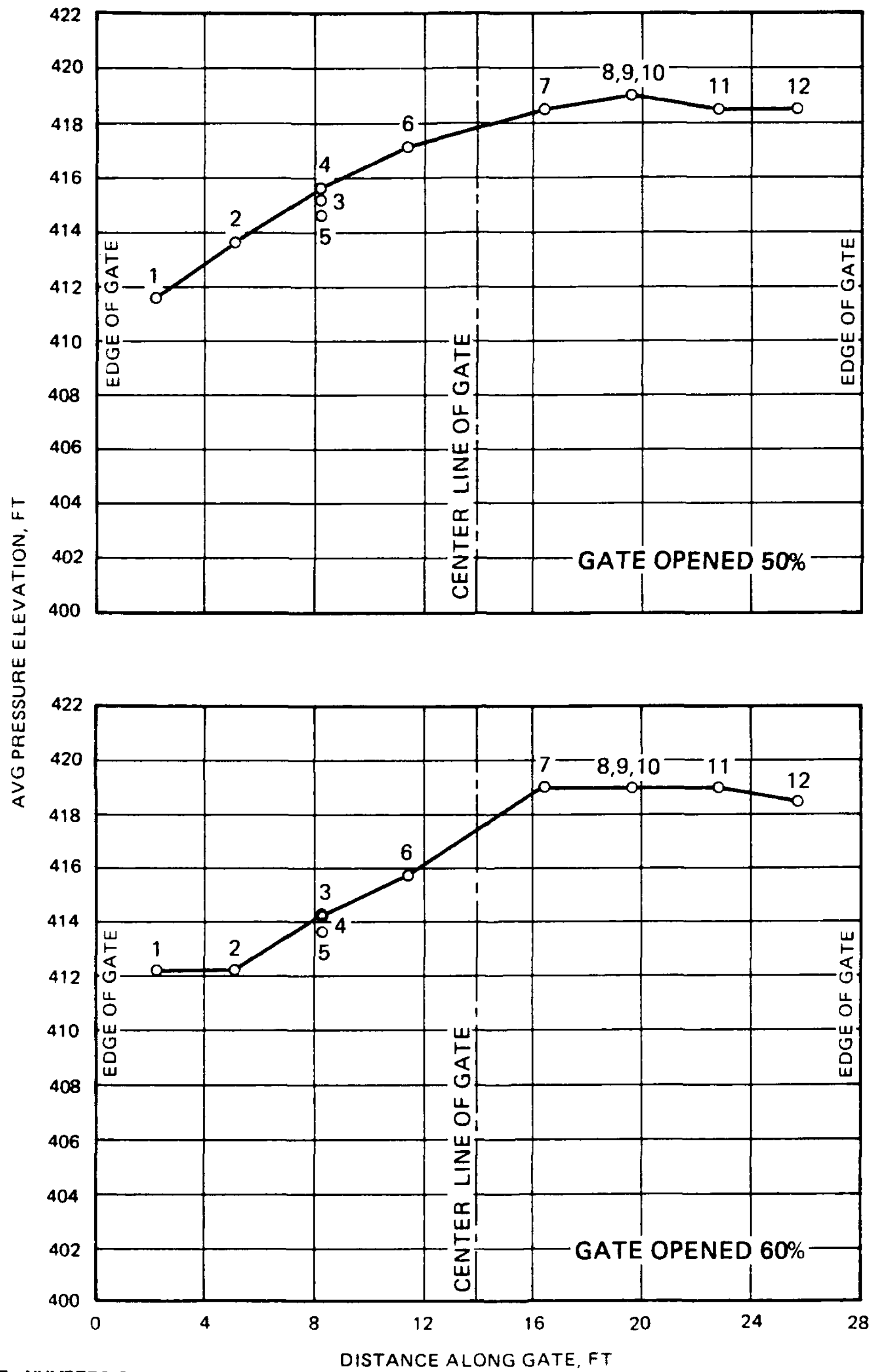
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 10 AND 20 PERCENT



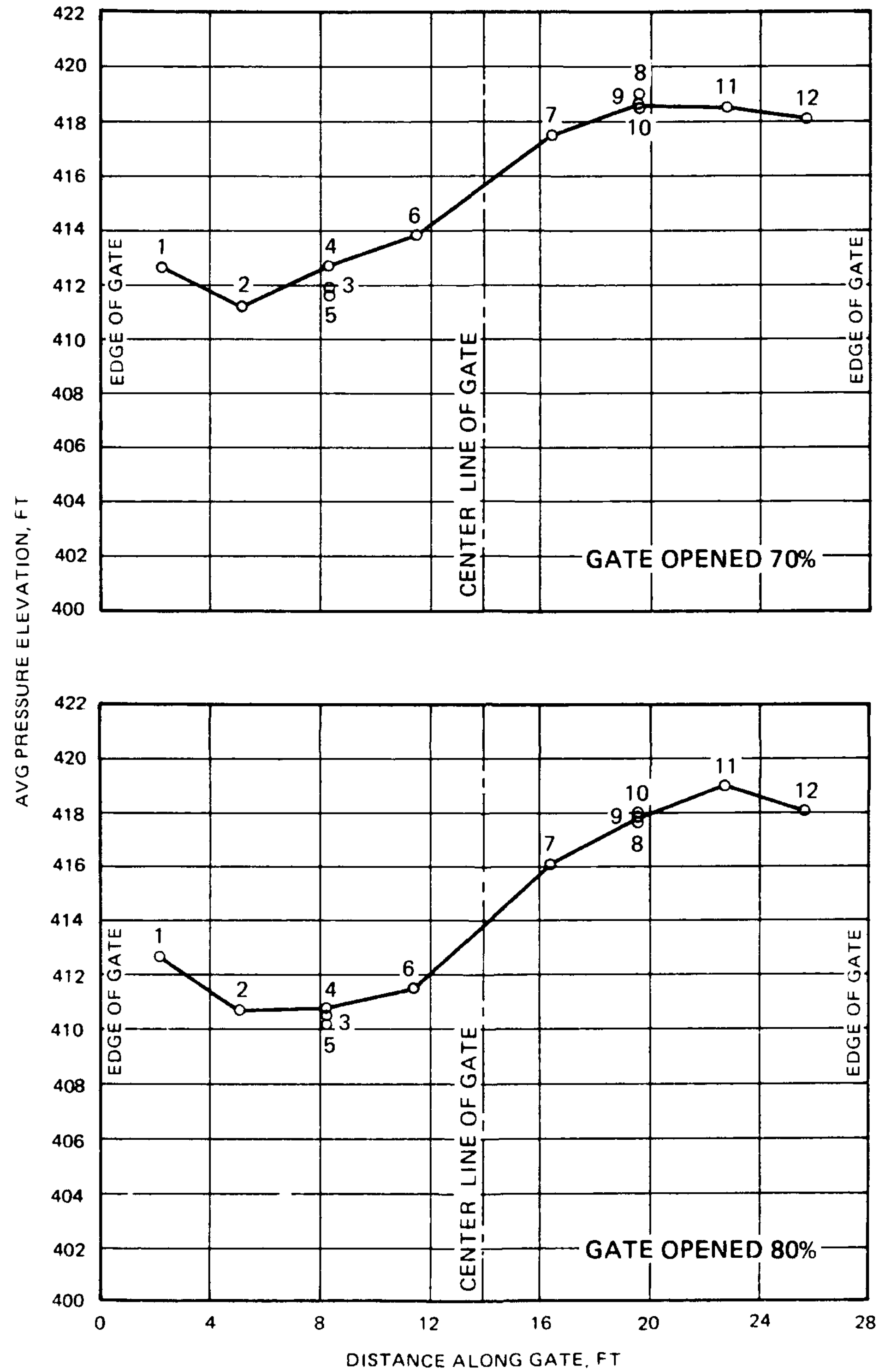
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 30 AND 40 PERCENT



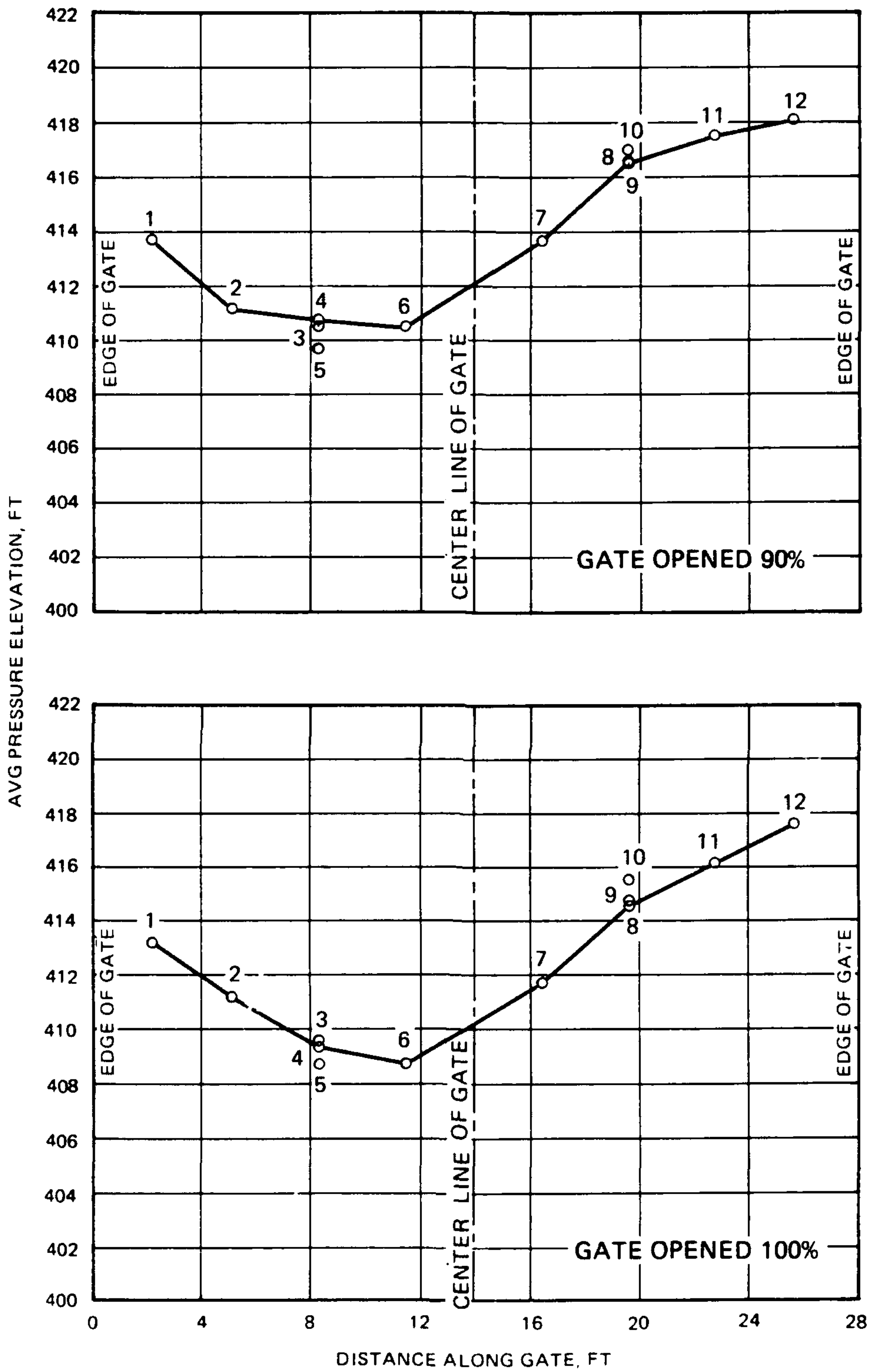
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 50 AND 60 PERCENT



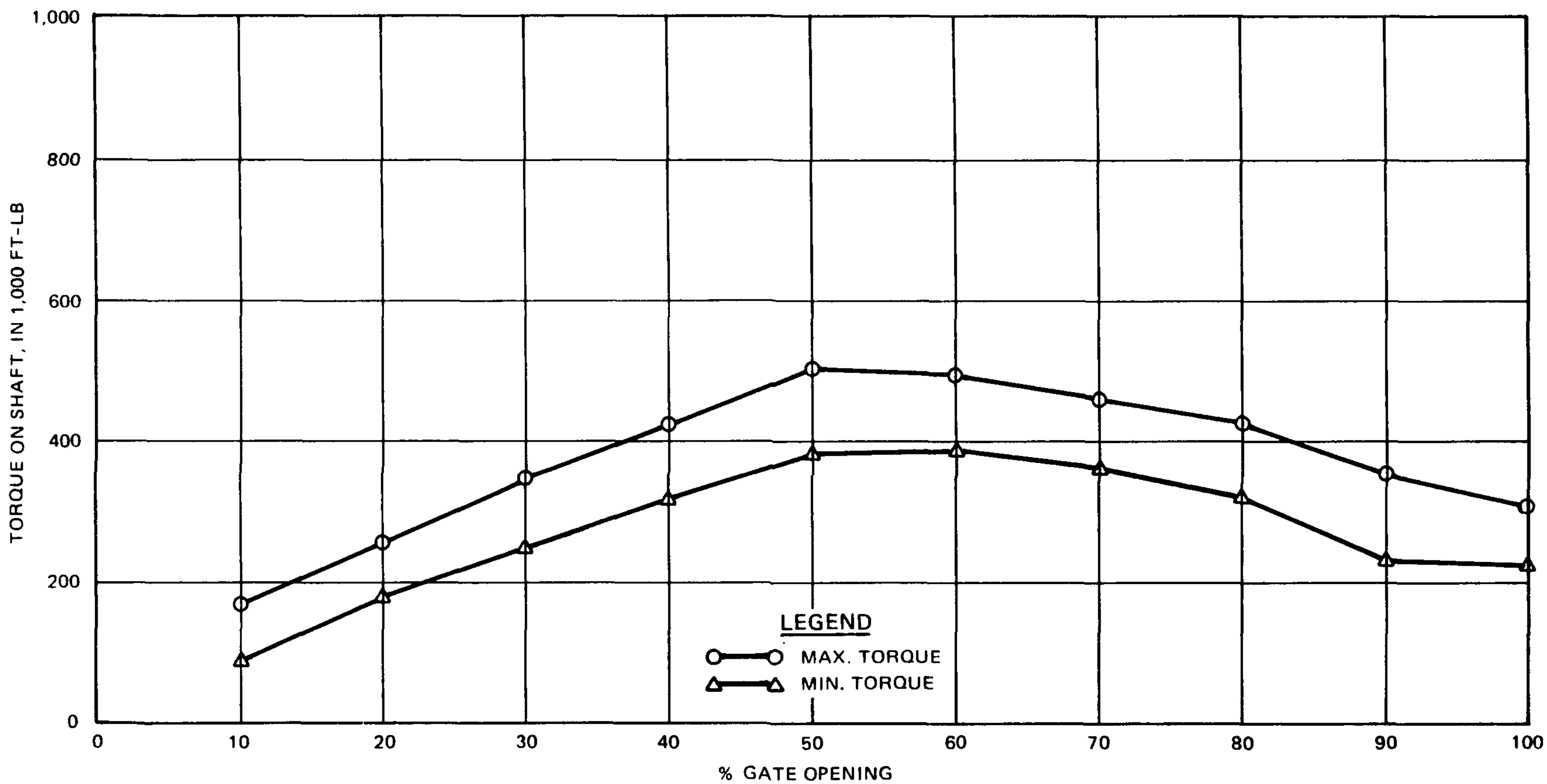
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 70 AND 80 PERCENT

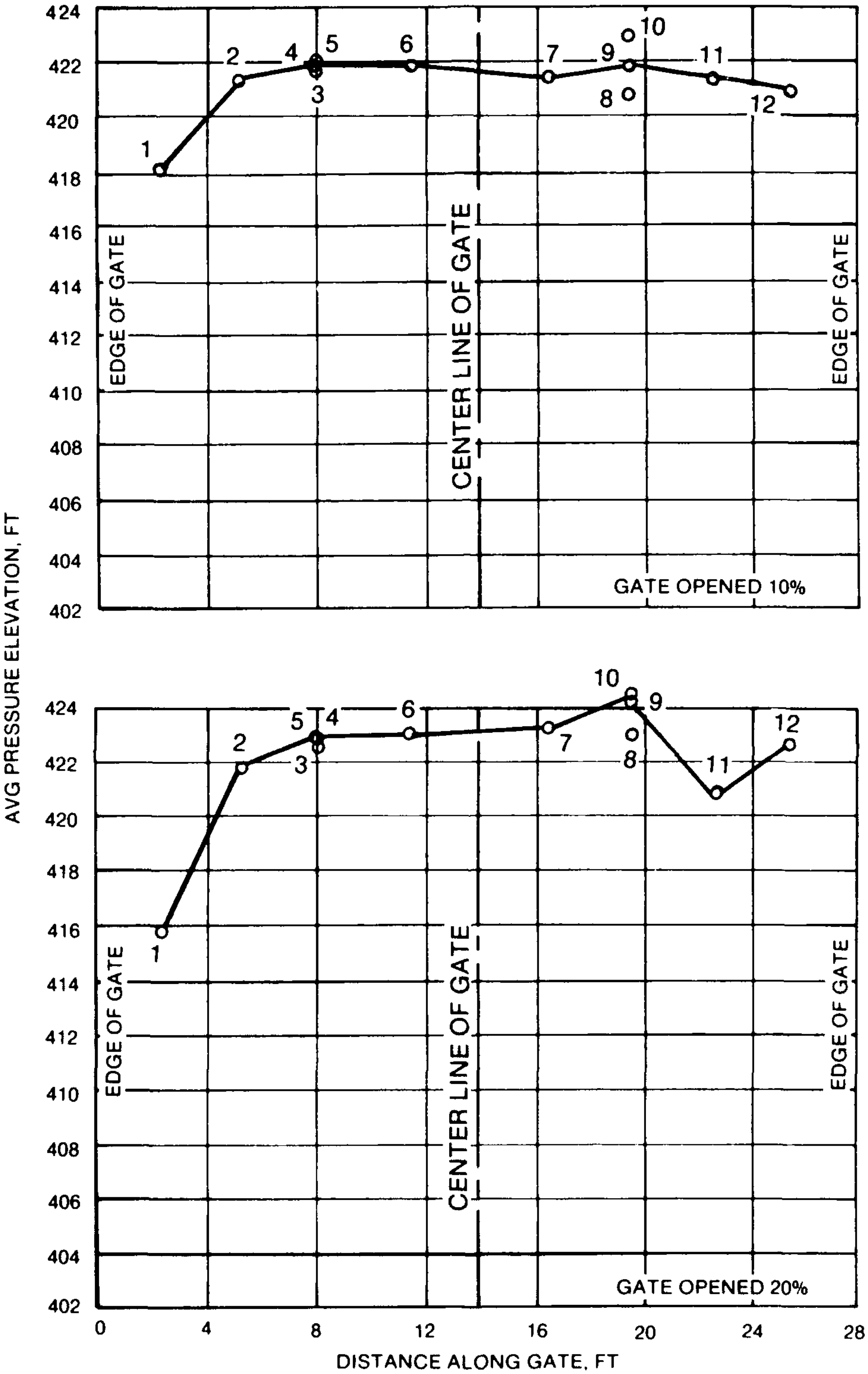


NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
2-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 90 AND 100 PERCENT

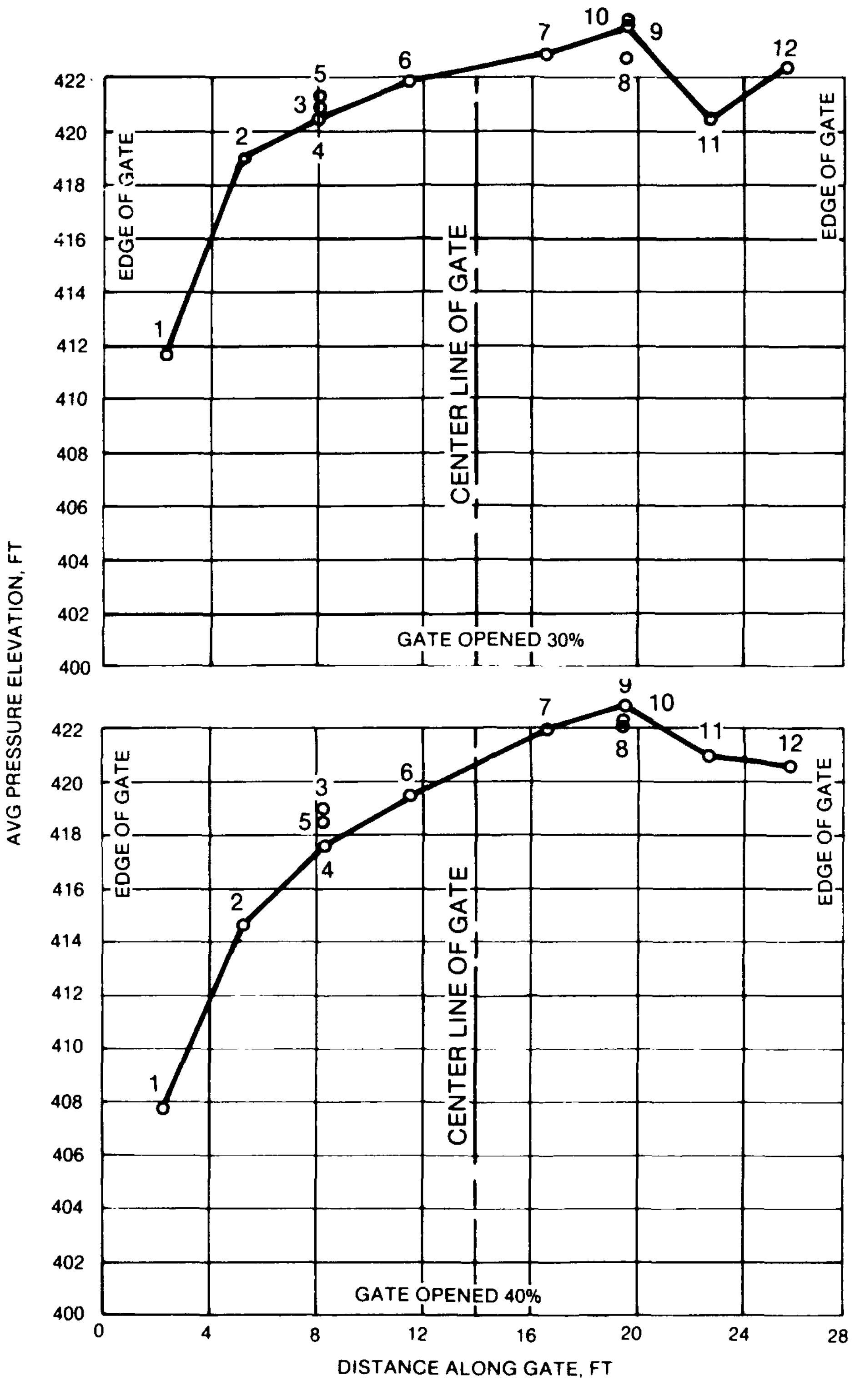


TORQUE VERSUS PERCENT GATE OPENING
2-MIN VALVE TIME
TAILWATER EL 403.0



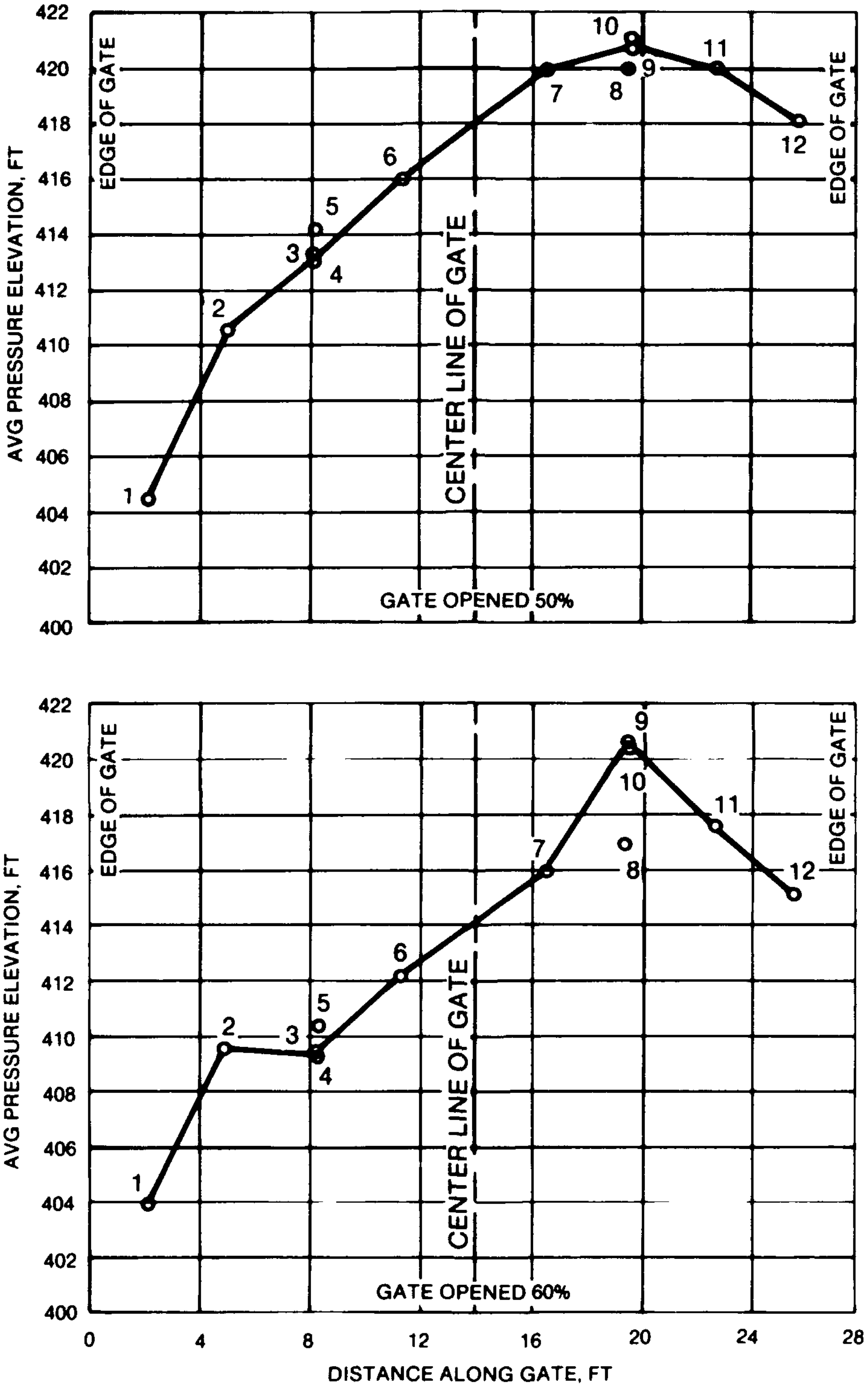
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 10 AND 20 PERCENT



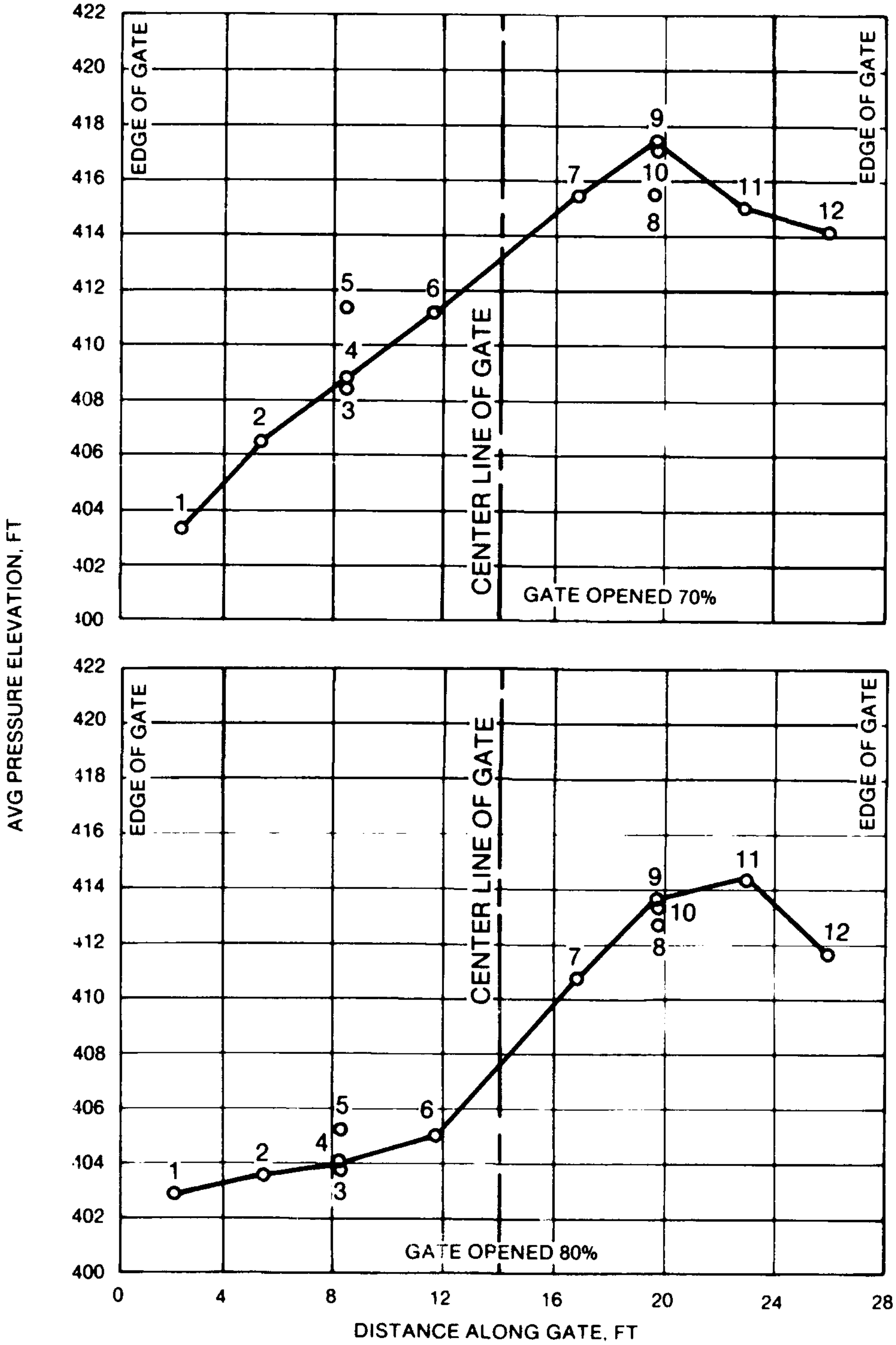
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 30 AND 40 PERCENT



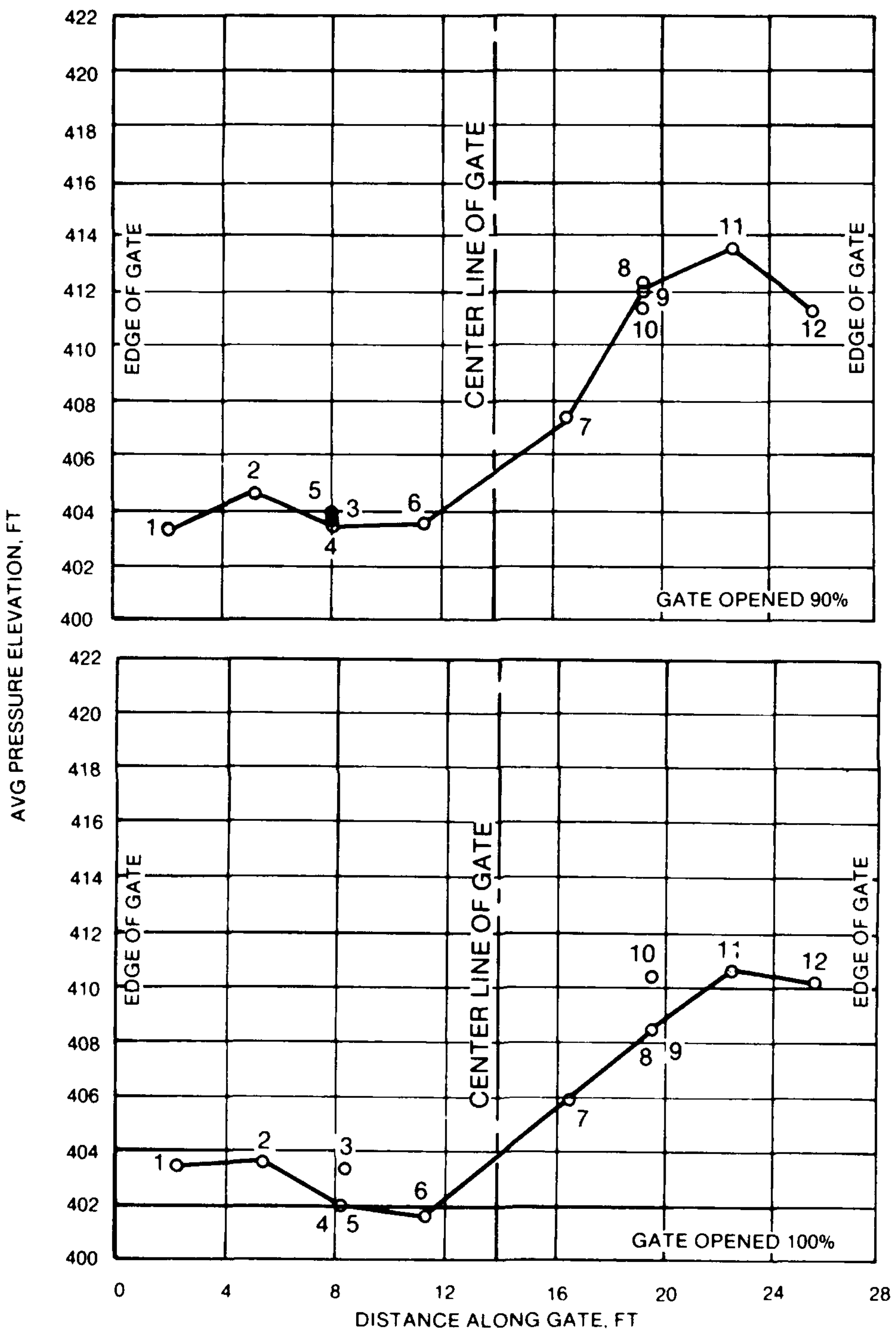
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 50 AND 60 PERCENT



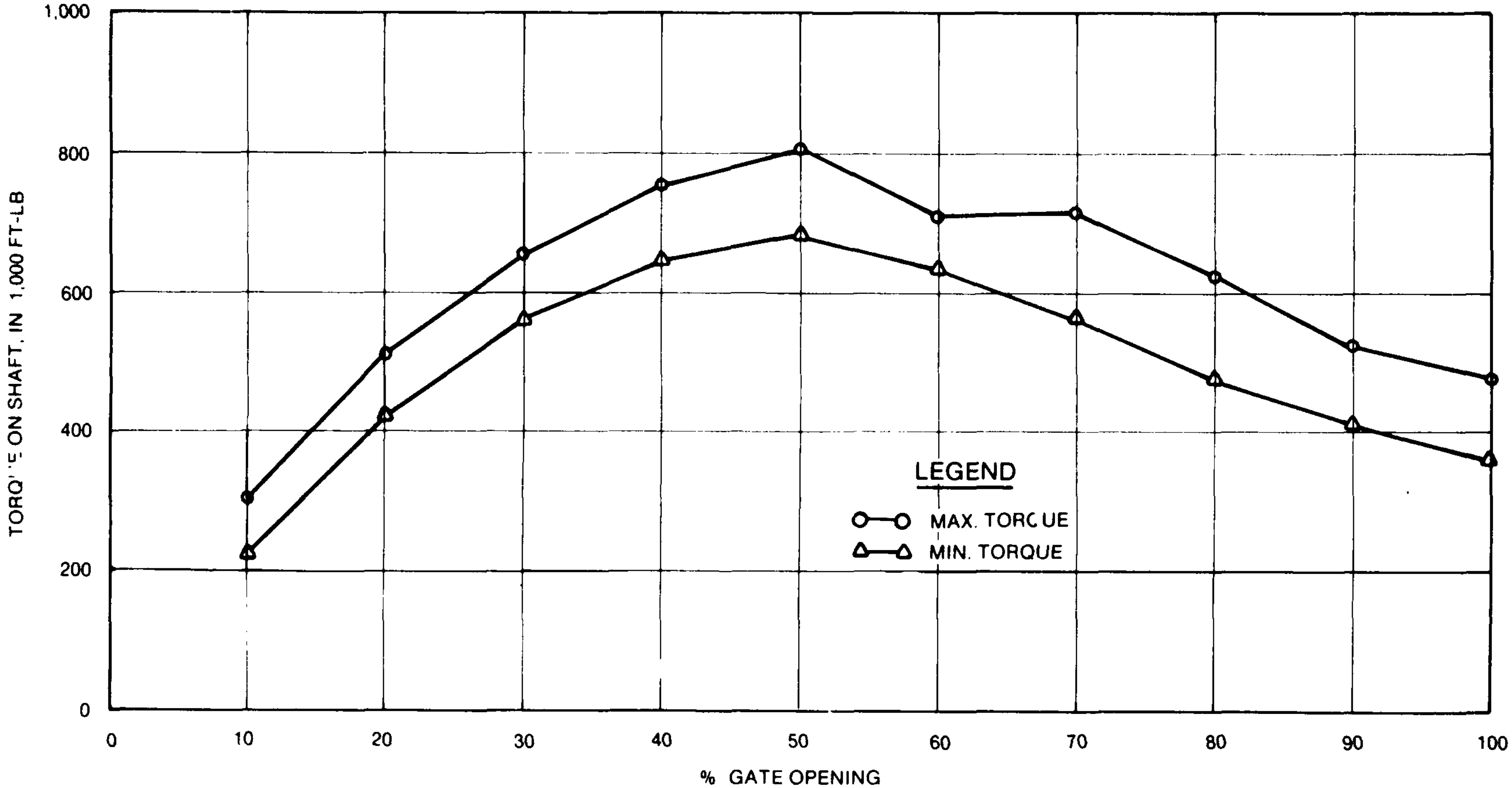
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 70 AND 80 PERCENT

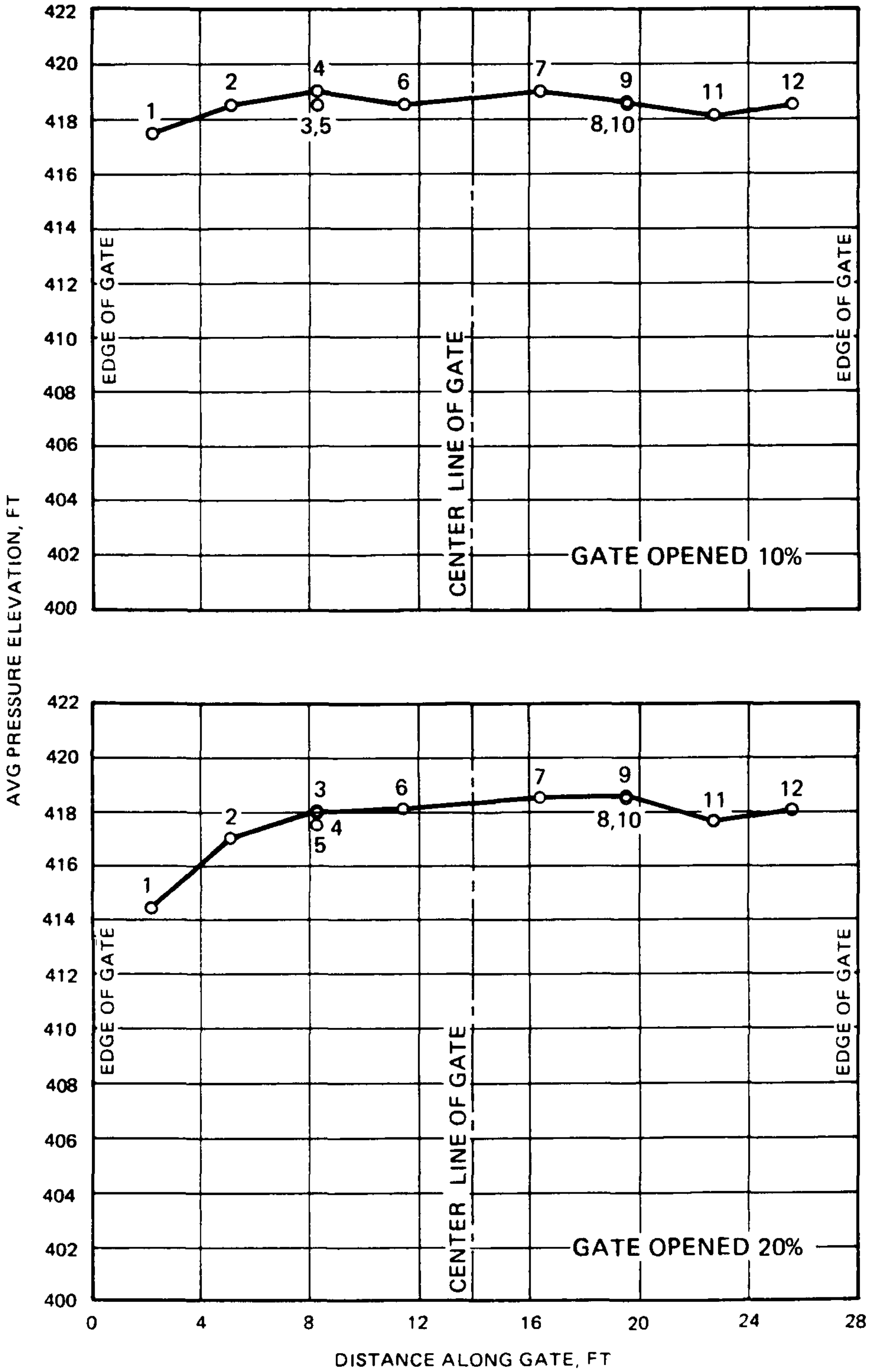


NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

**PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 395.0
GATE OPENED 90 AND 100 PERCENT**

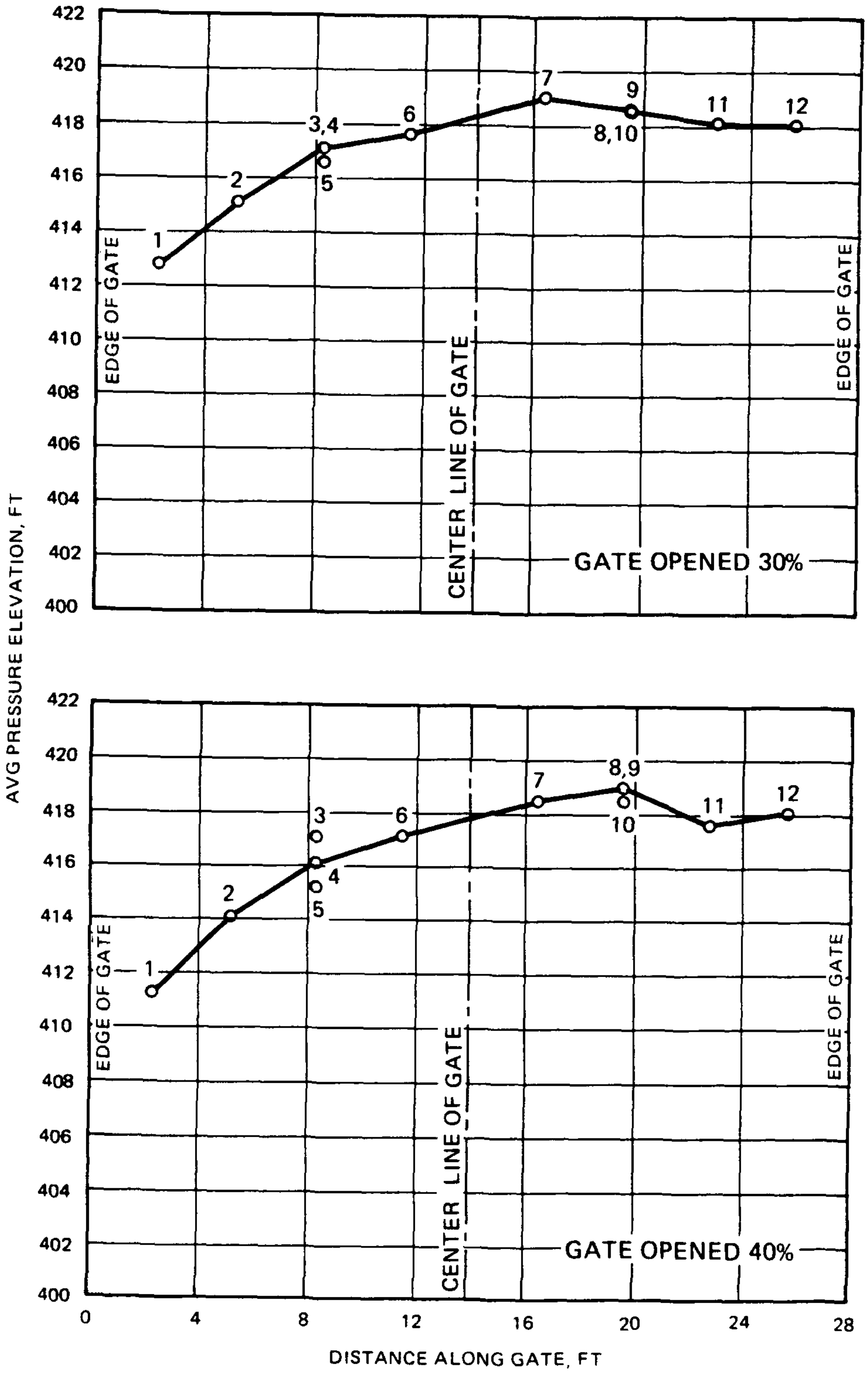


TORQUE VERSUS PERCENT GATE OPENING
4-MIN VALVE TIME
TAILWATER EL 395.0



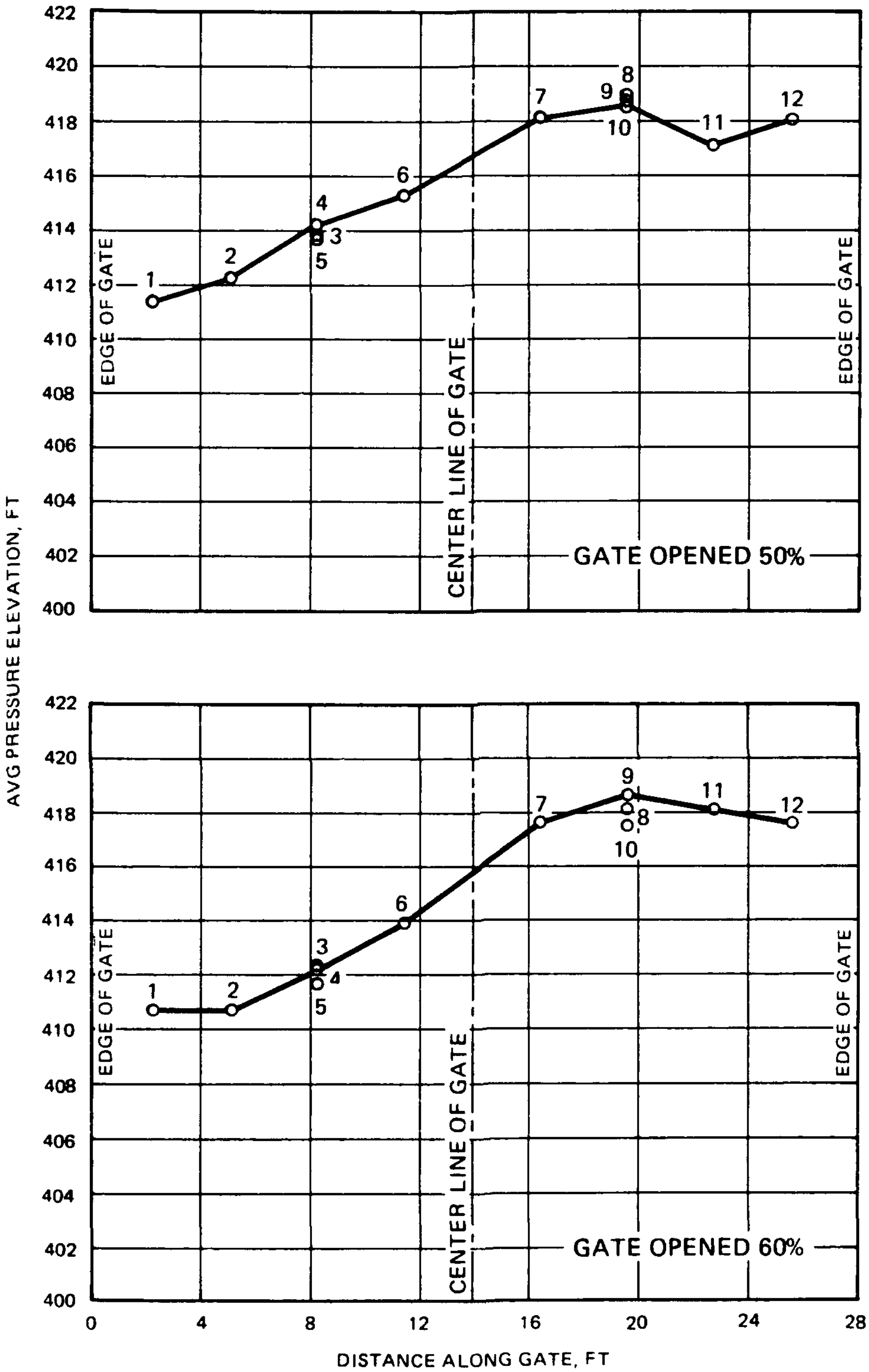
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 10 AND 20 PERCENT



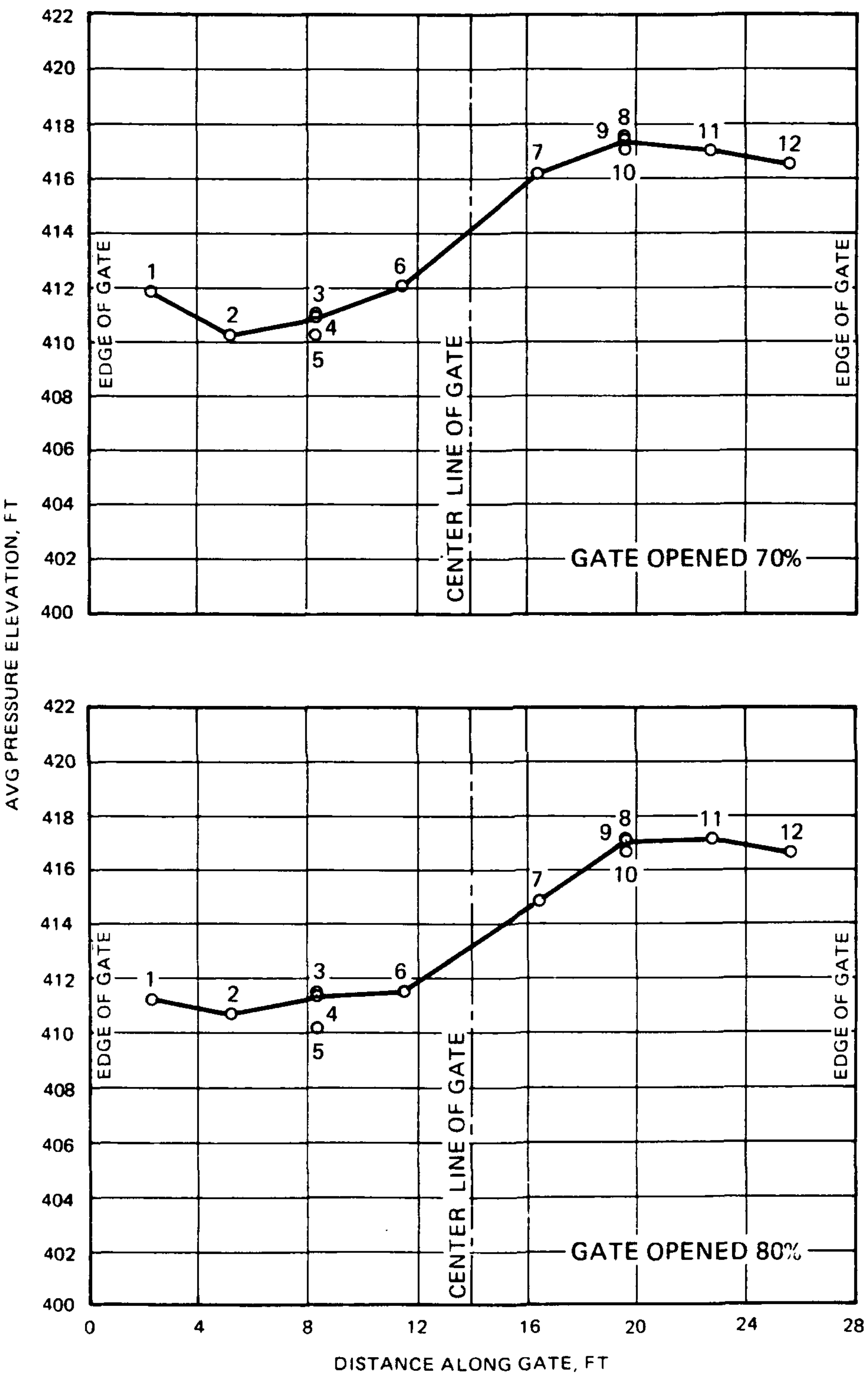
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 30 AND 40 PERCENT



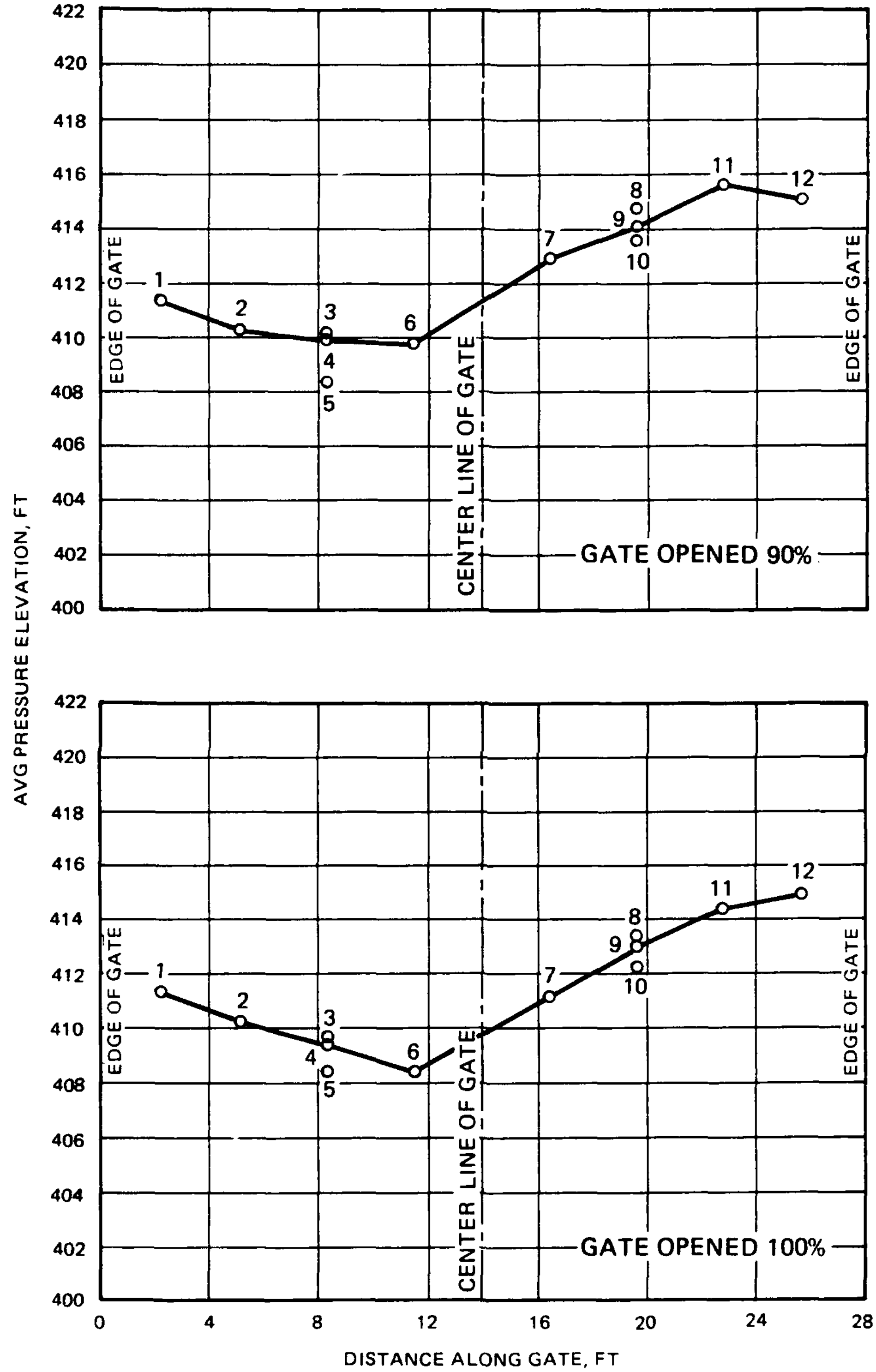
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 50 AND 60 PERCENT



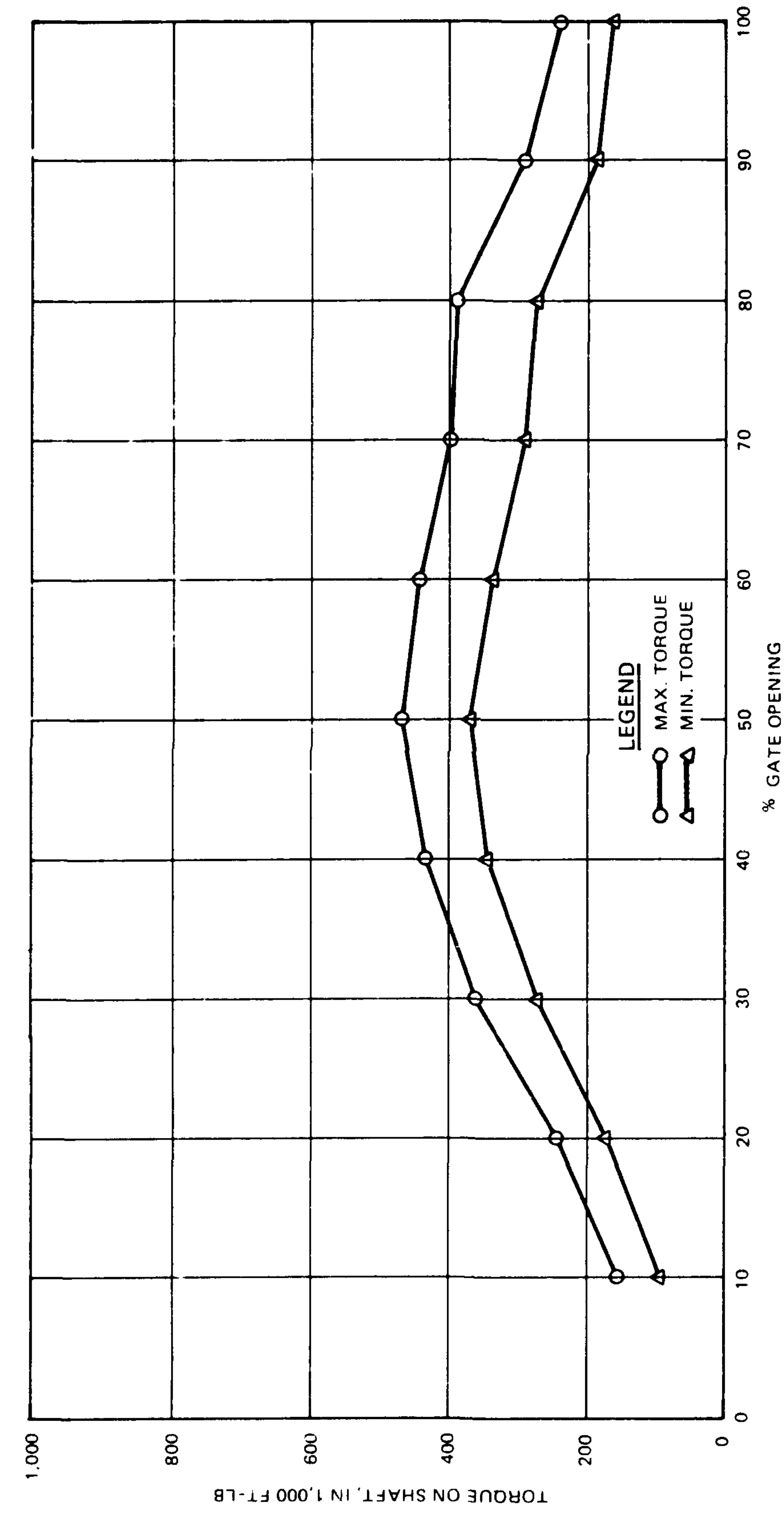
NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 70 AND 80 PERCENT



NOTE: NUMBERS ON PLOTS INDICATE PRESSURE CELL NUMBER.

PRESSURE ON FACE OF GATE
4-MIN VALVE TIME
TAILWATER EL 403.0
GATE OPENED 90 AND 100 PERCENT



TORQUE VERSUS PERCENT GATE OPENING
4-MIN VALVE TIME
TAILWATER EL 403.0